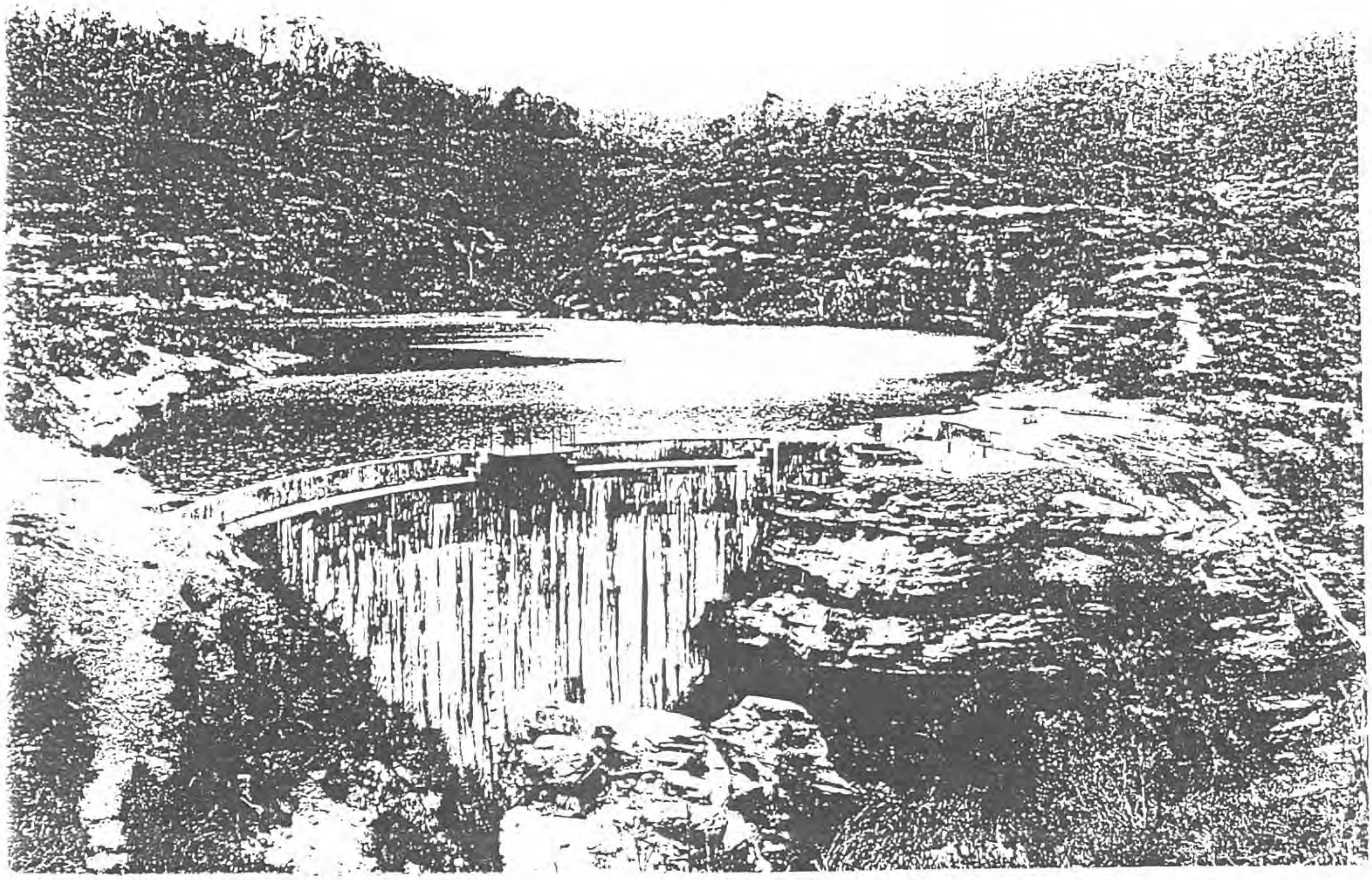
MEDLOW DAM, MEDLOW BATH



Submission for an
Historic Engineering Marker
from
The Engineering Heritage Committee
Sydney Division
Institution of Engineers Australia
1994

The Institution of Engineers, Australia

ESTABLISHED 1919 · INCORPORATED 1926
INCORPORATED BY ROYAL CHARTER 1938

SYDNEY DIVISION

ENGINEERING HERITAGE COMMITTEE

EAGLE HOUSE,
118 ALFRED STREET,
MILSONS POINT 2061

TELEPHONE: 929 8544

ALL CORRESPONDENCE
SHOULD BE ADDRESSED
TO:
THE SECRETARY,
BOX 138, POST OFFICE,
MILSONS POINT, 2061

Commemorative Plaquing
Sub-Committee,
National Committee on
Engineering Heritage.

12 April 1994

Dear Sirs,

HEM for Medlow Bath Dam

URGENT REQUEST

The New South Wales Country Engineers Convention has been organised for Saturday and Sunday, July 23-24 at Blackheath in the Blue Mountains. The village of Medlow Bath with its well-known Hydro Majestic holiday centre is just a few kilometres east of Blackheath. The Medlow Bath Dam is on the northern edge of the village.

The Saturday afternoon has been set aside for technical inspections and on Sunday morning they visit the Zig Zag and see the NEL plaques. The organisers have asked that the opportunity be taken on Saturday afternoon to plaque the Medlow Bath Dam, the thinnest concrete arch dam in the world when completed in 1907. However, they were not aware of the plaquing procedures and have left the arrangements rather late.

Fortunately, the Sydney Committee had recently received a copy of a report on Medlow Bath Dam, from a Sydney University student, that has been reworked by our committee member, Peter Allsopp, into an HEM submission. The dam is owned by the Sydney Water Board and approval has been received for the work to be plaqued.

I appreciate that the Plaquing Sub-Committee prefers more time to consider submissions but with the prospect of getting the heritage message before engineers and associates at an Institution function, I ask that the submission be treated as URGENT.

Regarding final wording or any other matter that will expedite arrangements, Peter Allsopp is available on FAX 02 906 4126 or myself on FAX 02 692 3343.

Yours faithfully,

Ian Bowie
Chairman.

Blue Mountains Country Convention

22 July - 24 July 1994

"Engineering Development & Tourism in a National Park"

Celebrating the Institution's 75th Anniversary

Venue: Redleaf Lodge Motel - Blackheath

Sponsored By...

PROSPECT ELECTRICITY

AWT AUSTRALIAN WATER TECHNOLOGIES

STRATEGIC CONSULTANCY DIVISION
DAMS SAFETY GROUP,
Level 7, 370 Pitt Street, SYDNEY 2000

DATE: 12/4/94.

NO. OF PAGES FOLLOWING: 1

FACSIMILE

TO: P. ALLSOPP

COMPANY/BRANCH/SECTION:

LOCATION:

TELEPHONE NO.:

FACSIMILE NO.: 906 4126

FROM: I LANDON-JONES.

BRANCH/SECTION:

LOCATION:

TELEPHONE NO.: 562 6330

FACSIMILE NO.: 562 6301

SUBJECT MATTER

Sorry for the rushed response. I will forward a more formal reply in due course.

To: H. Cowan - Engineering Heritage Committee, I.E.A.

From: I. Landon-Jones, S.D.E. Dams Safety Group.

Subject: Lake Medlow Dam.

Date: 12th April, 1994.

In regard to your letter of 30.3.94 concerning the conferral of an Historic Engineering Marker on Lake Medlow Dam as part of the Engineers Country Convention the Water Board is agreeable in principle to this proposal. The Manager Bulkwater the owner of the dam has given his endorsement.

Please provide further details as they become available so that any necessary arrangements can be made.

I. Landon-Jones.
S.D.E. Dams.

I E AUST

CREST

HISTORIC ENGINEERING MARKER

MEDLOW DAM

WHEN COMPLETED IN 1907 THIS DAM WAS THE MOST SLENDER ARCH DAM IN THE WORLD AND REPRESENTED AN INTERNATIONALLY ACKNOWLEDGED STEP FORWARD IN PIONEERING CYLINDRICAL CONCRETE ARCH DAMS. IT WAS A DARING AND INNOVATIVE DESIGN BY L.A.B. WADE AND WAS BUILT BY THE N S W PUBLIC WORKS DEPARTMENT AT A TIME WHEN AUSTRALIAN ENGINEERS WERE SHOWING GREATER INDEPENDENCE FROM BRITISH PRACTICE

DEDICATED BY
THE INSTITUTION OF ENGINEERS, AUSTRALIA
AND THE WATER BOARD. 1994

NAME OF WORK:	**MEDLOW DAM**
DESIGNED AND CONSTRUCTED BY:	**NSW PUBLIC WORKS DEPT**
ENGINEERING SIGNIFICANCE:	**MOST SLENDER DAM IN WORLD**
SOCIAL IMPACT:	**REPRESENTATIVE OF MEANS OF ECONOMICAL RURAL WATER SUPPLY**

Commemorative Plaque Nomination Form

Date: 1994

To:
Commemorative Plaque Sub-Committee
The Institution of Engineers, Australia
11 National Circuit
BARTON ACT 2600

From: ENGINEERING HERITAGE COMMITTEE
SYDNEY DIVISION

(Nominating Division or Branch)

The following work is nominated for an *Historic Engineering Marker/~~National Engineering Landmark~~ award:

Name of work: MEDLOW DAM, BLUE MOUNTAINS

Location, including address and map grid reference if a fixed work: See attached map
KH 494 723

Owner: WATER BOARD

In support of the nomination the following information is provided:

For an Historic Engineering Marker (HEM)

(1) Proposed wording on HEM# See attached

(2) Justification - please make data as complete as possible.#

See supporting papers

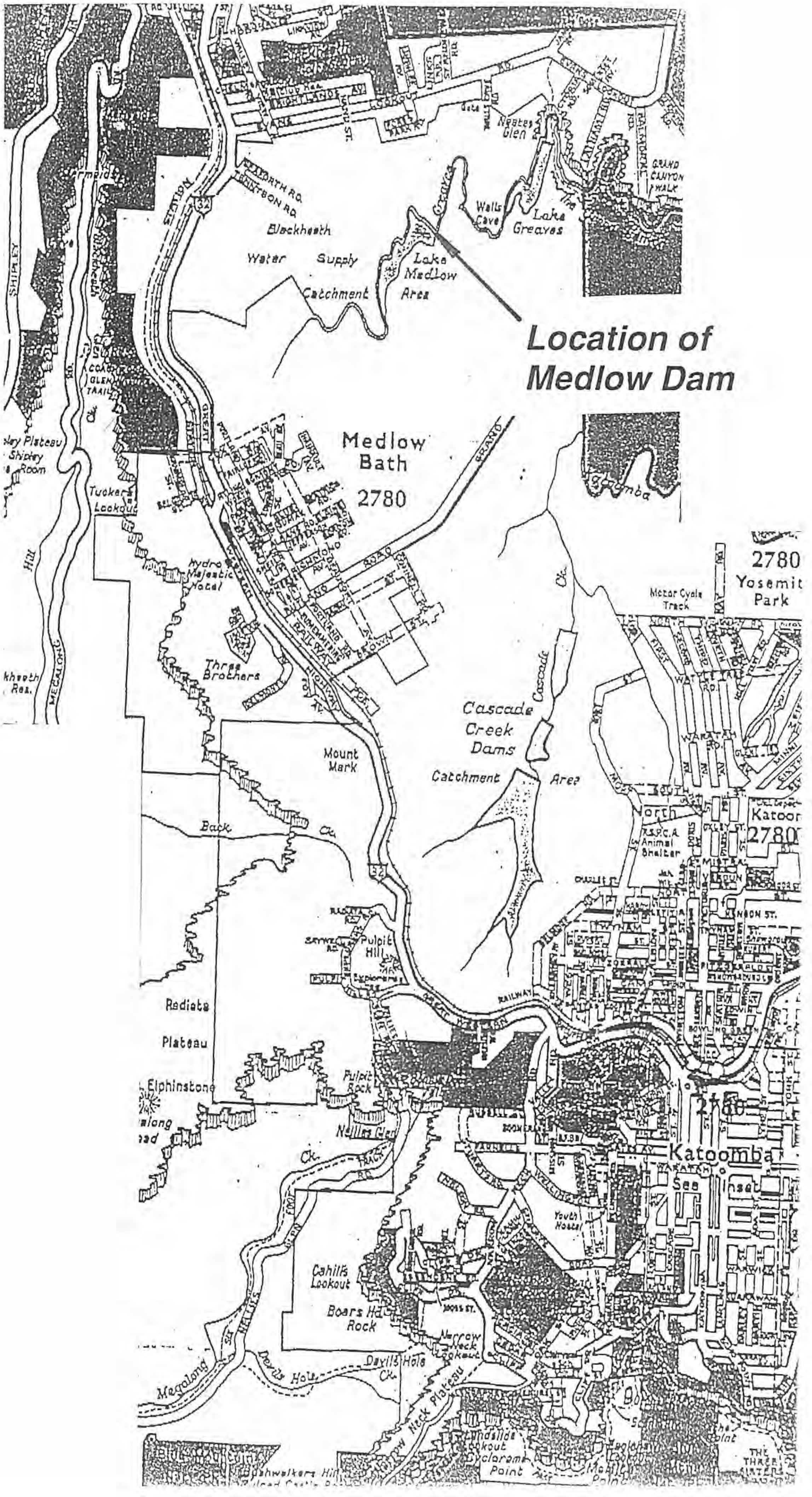
For a National Engineering Landmark (NEL)

(1) Date of construction (or other significant dates). N/A

(2) Names of key professional personnel associated with the work.# N/A

(3) Historic engineering significance of the work.# N/A

LOCATION MAP


Location of
Medlow Dam
Blackheath
Water Supply
Catchment
Lake
Medlow
Area
Walls
Cave
Lake
Greaves
Neates
Glen
GRAND
CANYON
WALK
Medlow
Bath
2780
Tuckers
Lookout
Hydro
Majestic
Hotel
Three
Brothers
Mount
Mark
Cascade
Creek
Dams
Catchment
Area
Cascade
2780
Yosemite
Park
Motor Cycle
Track
R.S.P.C.A.
Animal
Shelter
Katoomba
2780
Pulpit
Hill
Pulpit
Rock
Radiata
Plateau
Nellies Glen
Katoomba
Youth
Hostel
Cahill's
Lookout
Boars Hd
Rock
Narrow
Neck
Lookout
Devils Hole
Megalong
Narrow Neck Plateau
Landslide
Lookout
Cyclorama
Point
RAILWAY
SHIPLEY
MEGALONG

HISTORICAL ENGINEERING MARKER NOMINATION

FROM: Engineering Heritage Committee — Sydney Division

DATE: 12 April 1994

TO: Commemorative Plaque Sub-Committee
National Committee on Engineering Heritage
The Institution of Engineers, Australia
11 National Circuit
BARTON ACT 2600

The following work is nominated for an Historical Engineering Marker Award:

NAME OF WORK: Medlow Dam

LOCATION: On Greaves Creek 1km east of Great Western Highway between Blackheath and Medlow Bath

OWNER: Water Board
115—123 Bathurst Street
SYDNEY NSW 2000

In support of the nomination the following information is provided:

1. **Proposed Wording of HEM:**

WHEN COMPLETED IN 1907 THIS DAM WAS THE MOST SLENDER ARCH DAM IN THE WORLD AND REPRESENTED AN INTERNATIONALLY ACKNOWLEDGED STEP FORWARD IN PIONEERING CYLINDRICAL CONCRETE ARCH DAMS. IT WAS A DARING AND INNOVATIVE DESIGN BY L.A.B. WADE AND WAS BUILT BY THE N S W PUBLIC WORKS DEPARTMENT AT A TIME WHEN AUSTRALIAN ENGINEERS WERE SHOWING GREATER INDEPENDENCE FROM BRITISH PRACTICE

STATEMENT ON ENGINEERING SIGNIFICANCE

JUSTIFICATION

Selection from Group of Similar Dams

The Medlow Dam has been selected for nomination as being representative of the group of thirteen cylindrical concrete arch dams built in NSW between 1896 and 1908, which together attracted the attention of the international engineering community when they were first built. The principal reasons for its selection over the others are its height and extreme slenderness. The earliest of the group, built at Lithgow in 1896, was relatively small at 11 metres height and 70 Ml storage. The dams built subsequently were for the most part larger. The Cootamundra Dam, built in 1898, has a storage capacity of 600 Ml, with a height of 14m and a length of 150m. Medlow Dam has a height of 62ft = 19m and while the steep gorge in which it was built required it to have a crest length of only 97ft = 30m, it had a storage volume of 300 Ml.

Historical Engineering Context

The principle of an arched dam had been discovered and put into practice by the Romans. There are examples of Roman masonry dams in Glanum, France and Kasserine, Tunisia built in the early years of the Christian era.

Three cylindrical arch dams were built in Persia in about 1300 AD after the Mongol conquest. Because the Mongols had no engineering tradition of their own but relied on Chinese military engineers it may be supposed that arch dams were previously built in China, and may come to light in later archeological discoveries. One of the Persian dams was 60m in height, a dimension that was not exceeded in any dam until the twentieth century.

In 1384 a 15m high curved dam was built by the Moslems near Alicante in Southern Spain. In 1594 the 42m high Tibi Dam was completed also near Alicante. These dams were constructed of rubble masonry in lime mortar and had very thick walls in comparison to later true arched dams.

The first true arch dam was the Elche Dam, commenced in 1632 near Alicante. It was 23m high and had a slightly curved cylindrical main arch.

After the Spanish dams the concept of the arched dam was generally abandoned in favour of buttress, gravity and earth fill structures. One notable exception was the Ponte Alto Dam, begun in 1611 in northern Italy and progressively raised until it reached a height of 39m in 1887.

In 1826 Louis Navier, the noted French engineer and physicist, formulated for the first time a relationship between water pressure and material stresses in an arched water retaining structure. The French engineer Francois Zola refined this theory in the 1830's and evolved the principal of an arched dam the thickness of which varied with depth. The Zola Dam, at Aix-en-Provence, the only dam to be built to Zola's design, was commenced in 1847 and completed in 1854. It was thus the first arched dam to be proportioned according to scientific principles.

It is of interest to note that an arched sandstone dam was constructed in Parramatta to the design of Captain Percy Simpson in 1858, with a height of 12.5m and a length of 70m. It is doubtful however whether this was designed using Zola's principles. Its base width to height ratio of 0.29 approached that of a true gravity dam although it owed some of its stability to its arched construction.

Throughout the nineteenth century there had been a growing expertise at designing and constructing gravity masonry dams which relied upon their weight and monolithic

structure to resist the pressure of the retained water. The design principles were finally brought to the modern form by Professor Rankine in the latter part of the nineteenth century. By this stage the safe limit to the slenderness of a gravity dam became clearly established. It was also clear that there were substantial economies to be made in masonry content in arching the dam in plan, provided that the site afforded buttresses of hard rock that were no more than approximately 100m apart (the limit over which arching could be effective given the materials available at the time).

In 1883—84 the Big Bear Valley Dam was built for irrigation purposes in the San Bernadine Mountains of eastern California to a daring design by Frank Brown. It was by far the most slender dam that had been built to that time, being 20m high and 6m wide at its base, with a sharp taper. The dam attracted international attention, and not least from the design section of the relatively recently (1858) constituted Public Works Department of NSW. The Bear Valley Dam as it came to be known was only moderately curved, and despite the fact that it continued to perform adequately it was demolished in 1911 out of fear of the consequences of its failure and was replaced by a more conservatively designed buttress dam.

It had been the practice of the NSW Government to leave the planning and funding of water supplies to the local Municipal Councils involved. Concrete gravity dams had for example been constructed for the large towns of Orange, Armidale and Junee. The cost was however prohibitive for the smaller townships.

Concern about public health in the smaller towns led to the provision of water supply and sewage being taken over by the Public Works Department. However, the problem of a small population funding such major works remained.

During the drought and depression of the 1890's the then engineer-in-chief of the Public Works Department, Cecil Darley, examined the possibility of building thin all-concrete arch dams, in the light of the Bear Valley Dam experience, as a means of providing affordable water supplies to the smaller country towns. Sites with narrow gorges were selected and dams constructed along the lines of the Bear Valley precedent. Where the Bear Valley Dam had had bearing stresses on its abutments of over 4000kPa, the Public Works designs were limited to less than half this. However, the designs were progressively refined culminating in the unprecedentedly slender Medlow Dam. The designs were carried out by L A B Wade, an engineer with the Department who succeeded Darley in 1896 as engineer-in-chief for water supply and drainage.

Even at the time of construction the engineers responsible were aware that the theory as it then existed was too simple and could not accurately predict the actual elastic stresses or overall stability of the arched structures. It was felt intuitively however that bonding of the concrete into the abutments and the gravity restraint afforded by the curved structures would give an adequate margin of safety.

The design of the dams was an indication of the extent to which Australian civil engineers had broken with their earlier tradition of adopting British methods. Prior to this for example there had already been a change to American methods in the design of bridges.

When Darley presented a paper on the NSW dams to a meeting of the Institution of Civil Engineers in London in 1909 there were expressions of grave misgivings as to the safety of the designs. One engineer is reported to have called the design 'blood-curdling' while another more restrained commentator described the Medlow dam as "perhaps a little over-bold". Sir Alexander Binnie, president of the Institution, later encapulated the achievement of the Australian engineers when he stated:........*"It was not a matter of cavilling at theory or formulas; the dams had been built and were standing. The problem that now arose was for mathematicians to show how the strains were accommodated in such apparently narrow walls. That they were accommodated was a fact.........".* In other words, the Australian experiment was acknowledged at the time to be an integral and essential step in the evolution of the modern arched dam.

The construction of the NSW dams was studied with interest overseas, and true to Sir Alexander Binnie's prediction, it helped to spur the search for a more refined theory of arched dams. In the meantime cylindrical arched dams continued to be built in the USA, Sweden, Italy and other countries, emboldened no doubt by the pioneering work of Darley and Wade.

More recently (refer proceedings of 5th National Conference on Engineering Heritage 1990, MacKenzie Heinrichs and Coltheart) modern finite element analysis has indicated that there were (and presumably still are) vertical tensile stresses in the longer spanning examples of the group of thirteen dams, for example Lithgow No 1 and Mudgee dams. There were in fact horizontal cracks on the upstream faces of these structures. The analysis also showed however that upon loss of tensile strength the dam's arching would come into play to a greater extent and ensure an adequate factor of safety by the modern standards. In the case of Medlow Dam the short span did not allow tensile forces to develop to the same extent, and the intuition of the designers has been fully justified. The structure of Medlow Dam, as with all of the other older dams under the now jurisdiction of the Water Board, is carefully and regularly monitored, but so far there has been no sign of distress in any of the early arch dams. This is despite the fact that in some instances the dams have completely silted up, resulting in a considerable increase in incident horizontal pressure.

Medlow Dam continues to serve as a stand-by reservoir for the Blue Mountain communities.

STATEMENT ON SOCIAL IMPACT

OVERVIEW OF SOCIAL SIGNIFICANCE

The Greaves Creek location was considered initially as the site for a dam, not for any pressing local need for a water supply, as events were later to prove, but for its unusually narrow gorge composed of sound rock, which lay downstream of a capacious valley which could be used for water storage. None of Medlow Dam's twelve sister dams had such a high ratio of storage volume to dam width (see Table I). It was plain that the decision to build the dam was made on the basis of the economy with which a considerable storage facility could be constructed, coupled with the consideration that the population of the Blue Mountains area was growing and that the nearby community of Blackheath in particular would shortly warrant such a facility.

In fact Blackheath's population growth did not reach the earlier expectations and the dam was not commissioned or used for public water supply purposes for many years after its completion. When it was finally brought into operation as part of the Blue Mountains water supply it was only ever used as a back-up facility.

The details of the development and use of the dam are given in the following sub-section. The relatively low social impact of the Medlow dam in particular however should not obscure the important contribution that the family of dams it represents has made on Australian society. Medlow Dam has been chosen as being representative of the group of thirteen cylindrical concrete water storage dams designed and built by the NSW Department of Works in the period between 1896 and 1908. While all were of similar design Medlow Dam was the most daring, and best typified the innovative design approach adopted by the Department of Works. Together the dams provided cheap and reliable water supplies for eleven country communities and permitted their continued development. Funds would not have been available for a considerable fraction of these had conventional means been employed in their design.

Viewed in this light Medlow Dam has had a very important social impact. Details of the design attracted international attention among engineers and it represented an important step in the evolution of its modern efficient arched dam. As a consequence Medlow Dam made a contribution to affordable water supplies not only in Australia but throughout the world. It is instructive to refer to Table II which shows the chain of progression of arch dams worldwide prior to 1914. Medlow Dam and its sister dams formed a necessary link in this chain.

Notes on Events Leading up to Construction

In 1902 there were a series of meetings of representatives of Blackheath, Katoomba, Mount Victoria and Leura held to discuss obtaining a water supply for those towns. Schemes were suggested in conjunction with the Railways Department and both the Railway and Public Works Departments in the hope that the Railways would shoulder the capital costs. There was great concern that if this were not the case the rates for residents would be too high, as schemes built by the Public Works Department were reputedly very expensive. Also out of fear of the cost, many wanted a water supply only if it could be gravity fed, as pumps involved continuing costs.

At the first of these meetings, a Mr Corbett suggested the Walls Cave Creek as a potential source for the water supply. A visit to the site proved that a gravity fed scheme would not be possible but the water was abundant and pure, and the site was a natural reservoir so it would be ideal for a pumped scheme. This creek could only be what is now called Greaves Creek, and the site, which was above Wall's Cave, would be the site of the present Medlow Dam.

Throughout Blackheath residents were especially reluctant to commit to any expensive plan but agreed to inquire of the Government about the probable costs of a combined towns scheme to dam the Wall's Cave Creek and pump the water to Lookout Hill for distribution.

The major concern behind the demand for a permanent water supply was to maintain the prestige of the mountains with tourists. Economic losses had been experienced during recent dry spells, because cottages and rooms were unoccupied. Visitors accustomed to a regular supply expected in on their holidays. It was thought by the business people of the locality that the Mountains should have equivalent services to Sydney.

Nothing concrete came of this joint scheme. Katoomba residents continued to petition the Public Works Department for a water supply but those of Blackheath were not so concerned.

It at first appears a mystery why the dam at Medlow Bath was built. Neither the Public Works Department Records nor the local newspapers show that there was any petitioning of the Public Works Department by the local residents for a water supply for Blackheath or Medlow Bath. By comparison, the dam built at the same time in Katoomba was obtained after a great deal of such effort on the part of the residents there, all evidenced by frequent records in both these sources. There survives no contract for tender for the Medlow Dam, and no record of inquiry in the Standing Committee on Public Works Reports, as appear for both Lithgow and Katoomba.

In fact, Blackheath could not ask for Water Supply Works because it was not incorporated as a Municipality as was necessary under the Country Towns Water Supply and Sewerage Acts. As already mentioned above, the residents were more hesitant about the need for and cost of a water supply works when the idea first came up in 1902 and they did not go ahead with Katoomba.

As a solution to the prohibitively high cost of country town water supply works, the engineers of the Harbours and Water Supply branch of the Public Works Department were designing dams with a method used a few times in France and America — curved concrete walls. These dams were much thinner and therefore much cheaper than the gravitational dams previously built. The Carruthers Government provided some funds to be used to build Reservoirs for Country Towns to alleviate the problem as well. Medlow Dam was built using some of these funds when the Public Works Department were building two others in the locality. One dam in Lithgow and one in Katoomba were built in 1906, both using the same technique, so it was economical and convenient to also build the dam at Medlow. It was intended that the dam would supply Blackheath since it was believed that Blackheath would soon be incorporated, and thus legally able to own the Dam it would be taken over by the council.

Presumably the 1902 inquiries of the Public Works Department made by Katoomba and Blackheath together brought to that department's attention the ideal site on Wall's Cave Creek.

The labour used to build these dams was employed by the Public Works Department, and the Public Works Engineers oversaw the work rather than letting it out to tender, as it was in the nature of the design that it may need revision as work done revealed foundation conditions. Because of the innovative nature of the dams it was in the Department's interest to have a continuing work force which had developed experience with working on the cylindrical dams. Because this workforce was "day labour" coming from elsewhere just to do this job, the impact on the community at Medlow Bath would have been small.

Notes on Later Use of Dam

The dam had a capacity of 67 million gallons (later revised to 65), the wall was 62 feet tall, 97 feet long, with a curve radius of 60 feet. The thickness of the wall varied from 9 feet at the base to 3 feet 6 inches at the top. The catchment area was estimated at 1152 acres. It took until July 1908 to fill. The cost was 3245 pounds which worked out at a remarkably low rate per quantity of water.

The Public Works Department Records show that work was carried out to investigate the possibilities for the reticulation plan of Blackheath and Medlow Bath immediately after its construction. Inquiries were also made within the Public Service as to when Blackheath was likely to become a Municipality, and with the answer being possibly not for some time work on investigations and estimates was suspended.

In the *Daily Telegraph* of 18th June 1908 there appears a letter asking why the dam had not been put to use and suggesting Government inefficiencies in the building and utilization of the dam.

The chief engineer at the time, E M deBurgh, replied in answer to a Parliamentary question arising from the article, that —

> The Dam referred to at Medlow was not put in with a view to supply Blackheath or any other town, but with a view to improving the locality by the creation of a fine sheet of water, which might however be made use of in the future should a shortage of water occur in the adjacent Mountain Resorts, and should those requiring it be willing to pay the cost of pumping.

He went on to defend the management by the Department, and to describe the dam. He proudly mentions that it was perhaps the thinnest in the world and the cost per quantity of water impounded was very low. He finished by saying:

> The work is a great improvement to the locality and will, no doubt, be found of great utility in the event of recurrence of dry seasons on the Mountains.

A note attached to the answer says that the water was available to supply Blackheath and Medlow, but also formed a beauty spot, tourist attraction and fishing site.

Whether the answer that the dam was really to improve the aesthetics of the locality, and not for water supply, was an example of de Burgh's "characteristic Irish humour" or an unlikely excuse, it is clear elsewhere that the dam was intended as a water supply, but the implementation was delayed because Blackheath was not incorporated. However, the other comments about uses of the dam were also true. The dam was well used by tourists, walkers and fishermen from the time it was built until after the Second World War, when tourism generally in the Mountains declined. People also admired it for its beautiful appearance. The local newspapers used to list or illustrate tourist sites on their front cover and Medlow Dam frequently appeared as an attraction of the area. A leaflet entitled *The Blue Mountains at Medlow Bath* describes the walks that can be taken from the Hydro Majestic. Three go to Lake Medlow. The remains of these tracks, used by tourists to walk to the dam, survive as evidence to this pastime.

Periodically throughout the period 1907 to 1923 the Public Works Department received letters asking when the water supply will be made available and requesting that it be soon. One person who carried considerable influence was Mr Mark Foy who owned the Hydro Majestic, His letter prompted action in the form of a proposal for a scheme to supply the Hydro, the Railways Department and to be ready for the community at

Blackheath when it became a Municipality. The costs would have been too high for everyone concerned and the scheme did not proceed. Various other schemes were proposed and a long list of estimates and revisions were drawn up by the Public Works Department during the following years. Apparently Mark Foy tired of this process because in 1913, in accordance with the Minister's directions, he installed his own small plant to pump water to the Hydro Majestic and, at a small cost, to residents of Medlow Bath.

Meanwhile the residents of Blackheath were asking repeatedly for works to supply them with water from Medlow Dam, but as Blackheath was still not a Municipality it was not possible. The residents of Blackheath must have been very concerned about the water supply because in 1915 they asked whether a scheme similar to the one in Medlow Bath could be set up. This would involve the residents paying for the works directly. The Public Works Department preferred to wait until the legislation was changed or Blackheath became a Municipality.

In 1919 by Act of Parliament Blackheath became a Municipality, and in 1920 the Municipality of Blackheath requested that the Minister for Public Works move Parliament to refer to the Standing Committee the matter of the provision of works to supply Blackheath with water from Medlow Dam. The process was not quick and needed several representations to the Minister and the Premier to encourage it, but finally in 1923 the Blackheath Water Supply Act was passed, and then in the report of the Standing Committee in 1924 there appears the following results of an enquiry recommending that the works for Blackheath be carried out. The extract is given in full as it underlines the socially important role, not only that the Medlow Dam had the potential to provide, but that the other dams of its class and the dams that its example has made possible have continued to provide.

WATER SUPPLY FOR THE MUNICIPALITY OF BLACKHEATH

> In carrying out their enquiry the Committee have inspected portions of the catchment area and the storage of the Medlow water supply, from which it is proposed to draw water for the Blackheath Municipality. Evidence has also been obtained from representatives of the municipality and residents generally.
>
> The necessity for the proposed scheme is due principally to the increase in the number of buildings erected within the municipality during the last few years. At present there is no regular water supply, the residents obtaining water from roof catchments. The Railway Department however has a special supply from a dam at Govett's Creek to the local park and provides a service to the municipal gardens and two local hotels. This supply is liable to be cut off at a week's notice, and the Department has notified the local council that no further connections will be made.
>
> The supply to the municipal authorities by the Railway Department is inadequate to thoroughly water the streets and flush the gutters. Inconvenience is experienced in dry seasons owing to the tanks of the residents running out and involving the necessity of cartage from various springs in the neighbourhood of the town, at an approximate cost of 2s. 6d. per 100 gallons. The absence of water in case of fire naturally gives rise to apprehension amongst the population and results in an insurance rate on wooden cottages of 12s. 6d. per $100.
>
> In spite of the absence of a regular water supply the health of the town is good, the occurrence of notifiable diseases being confined to fourteen cases during the last seven years. In dry summer months however organic matter in the tanks is responsible for a number of diarrhoeal attacks, principally amongst young people. Very few breaches of the Health Act and Regulations have occurred during the last two years and these have been of a minor character.

> The maximum population provided for in the scheme for a period of years is 6,500 in the summer and 2,330 in the winter months. This population is inclusive of Blackheath and Medlow. The consumption of water is estimated at 330,000 gallons per day, the allowance provided for being 40 gallons and 30 gallons in the summer and winter months respectively — an annual total of 60,225,000 gallons. The capacity of the dam when full is 66,000,000 gallons which will give a supply on the basis mentioned and without any further rainfall for a period of twelve months, and this is regarded as ample for many years to come. It has been pointed out in evidence that the consumption quoted is a liberal one inasmuch as neither Blackheath nor Medlow contain industries requiring large amounts of water, and in the event of the scheme at any time becoming inadequate facilities exist for the erection of an additional dam below that now in use.
>
> The Committee are of the opinion that it is expedient the proposed scheme be carried out.

The work was started in 1925 and completed in 1927 costing the council 41,954 pounds including the capital cost of the Greaves Creek Dam downstream of the Medlow Dam.

The Railway Department agreed to take their water from the council supply and dismantled their own plant, much to the relief of some residents who thought it a blight.

It was not until 1940 that the total responsibility for care, control and management of Medlow Dam moved from the Public Works Department to the Blackheath Municipal Council.

In 1924 there had been a dry spell that caused much concern to the residents of the Mountains. In the *Katoomba Daily* appear pieces and letters expressing alarm about the water supply, especially any related drop in revenue from visitors. The council decided that if a shortage arose they could connect up pipes to Lake Medlow in a matter of days. The pipes were made ready but no such action was required as a period of bad weather successfully filled Katoomba Dam to overflowing.

In 1980 responsibility for the Blue Mountains Water Supply moved from the Blue Mountains City Council to the Water Board. Water from five dams in the Grose River Tributaries (of which Medlow is one) supply the upper Mountains, and a main takes water from this system to a service reservoir for the lower Mountains. The Medlow Dam is still in use in that water flows through the dam, over the overflow and is collected in the Greaves Creek Dam from where it is pumped to Medlow Bath and Blackheath. In this capacity it is not really functioning since the same would occur if it were not there. However, if the Greaves Creek Dam equipment were to malfunction the Medlow Dam pump could be recommissioned and the water pumped straight from Medlow Dam (this has not occurred for 3 years). In times of water shortage water can be siphoned off Medlow Dam into Greaves Creek to supplement the supply.

Investigation of the local papers over recent years shows that the Dam is still of importance to the local residents. This importance is largely in terms of it as a source of water, although its appearance in the register in the Blue Mountains Heritage Study shows that it is valued for additional reasons.

TABLES OF DAM COMPARISONS

TABLE 1

COMPARISON OF GROUP OF THIRTEEN NSW DAMS

APPENDIX I - CYLINDRICAL ARCH DAMS CONSTRUCTED IN NEW SOUTH WALES TO 1908 (WADE 1908; DE BURG 1917)

Fig. No. Pl. 1	Locality	Maximum Height above Foundation	Total Length	Top Thickness	Depth below Crest of Top Thickness	Thickness of Base	Surcharge allowed for	Radius of Curved Part	Limit of Pressure in	Approximate Storage	Character of rock forming site and used in construction	Date of Construction	Remarks
		FEET	FEET	FEET	FEET	FEET	FEET	FEET	TONS PER SQ FT	GALLONS			
	Parramatta	52.0	225	4.8	0	15.0	2.0	160	15	130,000,000	Sandstone	-	Original height 41 feet of masonry in Roman cement, built 1858, raised to 52 feet with concrete in 1898.
1	Lithgow No. 1	35.0	178	3.5	3.5	10.88	3.5	100	10	15,000,000	Sandstone	1896	
2	Parkes	33.5	540	3.0	6.0	13.5	5.0	300	24	114,000,000	Granite	1897	
3	Cootamundra	46.0	640	3.0	8.0	13.0	1.0	250	25	136,000,000	Granite	1898	
4	Picton	28.0	112	7.01	0	13.62	10.0	120	12	14,000,000	Sandstone	1897	Constructed to be raised 14 feet when required
5	Tamworth	61.0	440	3.0	3.0	21.5	2.0	250	20	50,000,000	Granite	1898	
6	Queen Charlotte Vale	32.0	113	3.0	6.0	8.65	2.0	90	10	-	Quartzite	1898	
7	Wellington	48.0	350	3.0	7.0	10.0	2.0	150	20	27,000,000	Conglomerate	1899	
8	Mudgee	50.0	498	3.0	5.0	18.0	1.0	253	20	42,000,000	Altered slate	1899	
9	Wollongong	42.0	535	3.5	5.0	11.62	1.0	200	20	160,000,000	Basalt	-	
10	Katoomba	25.0	320	3.0	7.5	20.29	1.0	220	15	34,000,000	Sandstone	1905	Constructed with buttresses. Ultimate height 50 feet.
11	Lithgow No. 2	87.0	221	3.0	3.0	24.0	3.0	100	10	88,000,000	Sandstone	1906	
12	Medlow	65.0	124	3.5	21.0	8.96	3.0	60	12	66,800,000	Sandstone	1906	
13	Mittagong	30.0	173.9	3.6	12.0	6.28	3.0	100	12	7,500,000	Sandstone	1908	

TABLE 2

CHRONOLOGICAL COMPARISON OF NOTABLE CYLINDRICAL ARCHED DAMS

(extract from *Water Power and Dam Construction*, Oct 1978)

[illegible] 1—Data on arch dams built up to World war I[1]

ame	Country	Period of construction	Height (m)	Length (m)	Structural characteristics[2] L'/H	B/H	R/C	Ø
ume	France	Roman	12	18	1·5	0·32	4	73
ara	Turkey	ca. 550	?	?	?	?	7	?
ebar	Iran	ca. 1300	26	55	0·8	0·35	6	40
urit	Iran	ca. 1300	60[3]	27	0·4	?	?	?
bbas	Iran	ca. 1300	20	?	?	?	?	?
che	Spain	1632–?	23	120	3·0	0·50	7	67
lleu	Spain	17th century	27[4]	23	0·9	0·37	6	22
nte Alto	Italy	1611–1887	39	12	0·3	0·10	4	46
nes Falls	Canada	1828–31	19	107	5·6	0·44	8	115
la	France	1847–54	43	66	1·5	0·34	9	77
ramatta	Australia	1856/98[5]	16	69	4·3	0·29	33	80
druzza	Italy	1883	41	15	0·4	0·14	5	52
ar Valley	USA (California)	1883–84	20	91	4·7	0·31	105	46
etwater	USA (California)	1886–88	30	116	3·9	0·50	18	100
worth	Australia	1898	20	134	?	0·33	83	100
gee	Australia	1899	15	152	10·0	0·22	84	117
llington	Australia	1899	15	107	7·0	0·20	50	133
[illegible]	Italy	1898–1900	38	40	1·0	0·46	?	?
per Otay	USA (California)	1901	23	86	3·7	0·16	90	60
ossa	Australia	1899–1903	36	144	4·0	0·29	45	136
gow 2	Australia	1906/15[5]	27	68	2·5	0·27	29	126
llow	Australia	1907	20	30	1·5	0·14	17	78
wley	USA (Oregon)	1908/15[5]	28	49	1·8	0·10	22	181
pang	Sweden	1908	21	90	2·6	0·14	13	80
finder	USA (Wyoming)	1905–09	65	132	1·4	0·45	14	72
Serra	Italy	1907–09	44	46	1·0	0·33	11	80
[illegible]	Sweden	1909	25	58	2·3	0·20	27	85
Bill	USA (Wyoming)	1905–10	99	61	0·6	0·33	15	80
[illegible]	USA (Colorado)	1908–10	29/22[6]	107	4·9	0·38	162	62
[illegible]	USA (N.M.)	1910	15	64	4·2	0·31	62	49
Crow	USA (Wyoming)	1910–11	19	46	2·4	0·19	19	111
[illegible]	Mexico	1911–12	30	56	1·4	0·18	20	106
[illegible]	Philippines	1912	30	70	2·3	0·13	35	116
[illegible]	USA (California)	1912	24	142	2·9	0·21	16	99
4	USA (California)	1912–13	24	67	2·8	0·35	?	?
[illegible]	USA (California)	1913	15	45	3·0	0·38	?	60
Creek	USA (Alaska)	1913–14	51	195	3·8	0·25	55	114
[illegible]	Italy	1313–14	38	81	1·7	0·18	15	158
[illegible]	USA (California)	1913/16/19[5]	84/64[6]	244	2·8	0·46	44	76
[illegible]	USA (Washington)	1914/18[5]	26	123	4·7	0·12	42	?

[illegible] only dams of over 15m height
[illegible] length of arch, excluding wing walls or artificial abutments, H = maximum height, B = base width, R = radius of crest arch, C = crest width, R/C = slenderness
[illegible] central angle of crest arch (degrees)
[illegible] heightening by 4m about 1850
[illegible] heightening by 5m in 1879
[illegible] heightening, to which structural characteristics are referred
[illegible] above gravity base, to which structural characteristics are referred

TECHNICAL PAPERS

The evolution of the arch da

By N. J. Schnitter*

PART ONE

The development of arch dams, like that of so many other structures and techniques, was m determined by experience, which more often than not preceded the development of the pert theories. This account emphasizes the structures marking the principal technical innovations and t concepts leading to the methods most widely used today. Furthermore the presumable or pro transfers of the technology between different regions and periods are stressed, as well as t internationality of its extraordinary development and propagation in the present century.

The forerunners

THE FIRST DAMS go back to the earliest civilizations, the very formation of which was often conditioned by the need for large hydraulic works[1]. The early structures used the more obvious force of gravity to resist the water pressure and were mostly of the earth or rockfill type. These were also preferred by the Romans who appear, however, to have introduced the arch into dam engineering, which they used with such mastery in their buildings and bridges. The corresponding evidence is rather sparse and mostly circumstantial. This is especially true for a small dam in the Vallon de Baume south of Saint-Rémy de Provence in France. Its foundations were discovered and recorded in the 18th century[2], but are now almost completely covered by a curved gravity dam built on the same site in 1891[3]. An old drawing shows that the ancient dam was a relatively strongly curved, sturdy cylinder and consisted probably of two concentrical masonry walls with an impervious earth core in between, as may still be observed at the ruins of the Roman gravity dams near Orükaya and Cavdarhisar in Turkey[4]. Its maximum height must have been about the same as that of the present structure, ie, some 12m†. Roughly at mid-height was the intake for a lead pipe, which carried the water from the small reservoir to the colony of Glanum a few hundred metres to the north.

Several centuries later we find evidence that the basic principle of the arch dam was well understood by the Roman engineers. Procopius of Caesarea relates in his *Buildings* (book II, chapter 3), that when Chryses of Alexandria was commissioned by the Byzantine emperor Justinian I (527-565) to erect a flood control dam for Dara near Mardin on the Turkish-Syrian border, "he did not build this barrier in a straight line, but in the form of a crescent, in order that its arch, which was turned against the stream of the water, might be better able to resist its violence". Nothing else is known about this dam but a picture (Fig. 1) published by A. Poidebard may represent its remains[5].

With the breaking up of the Roman empire and its cultural and economic ties, dam building came to a standstill in the western world, while it continued to flourish in Japan, southern India, Sri Lanka, Arabia and Iran. Especially noteworthy in the present context are the developments in the last mentioned country, since they established a firm tradition in the construction of masonry dams, highlights of which were the Sassanian (3rd century) weir-bridge combinations in the Khuzestan province, the Bujid (10th century) gravity dams for the operation of water-mills in Fars and the Ghasnawid (12th century)

† For additional structural data see Table I.

* Executive Vice-President Motor-Columbus Consulting Engineers, Baden, Switzerland.

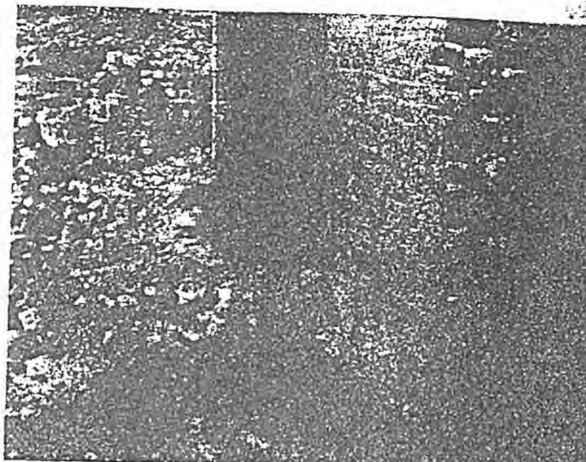


Fig. 1. The probable remains of a flood control dam on the T Syrian border built by Chryses of Alexandria (527-565).

gravity dams in Khurassan. The theme was again under the Mongol Ilkhans towards the end 13th century, when they reconstructed the ravaged half a century earlier by the onslaught of conquering armies.

Among the Iranian dams from the Ilkhanid peri also some arch dams, the oldest still existing of this type. Best known is the Kebar dam, 160km of Tehran[6] (cover). It has a maximum height of its sturdy central part shows a modest curvature its upstream face is a vertical cylinder, the dow face is inclined so that the thickness of the increases from 6m at the crest to some 9m at the the dam. The masonry consists of limestone block a lime mortar containing ash from thorn bushe like pozzolanas, gives the lime hydraulic propert to the right abutment a spiral staircase descend 10m into the dam, which has several opening upstream face at different levels and a downstrea at the bottom. Thus, the withdrawal of water wa even as the relatively small reservoir silted up prog

Less well researched but even more remark Kurit arch dam in southern Khurassan, 620km of Tehran, which is more than twice as high and held the world height record of all dam typ the beginning of the 20th century[7] (Fig. 2). It is in a narrow gorge and is also completely silted of the vertical downstream face is badly damag exposing a shaft and other openings as well as the

masonry as is found at Kebar. Some 40km north- the Kurit dam there is a smaller similar structure after Shah Abbas (1587-1629), but dating from the l period[7]. The dam is likewise located in a narrow the bottom of which was, however, not cleared tely before construction of the dam. Upon filling reservoir, the alluvium left in place washed out r with the lowest part of the dam, the remainder ch was underpinned with a brick vault under the ls in the 16/17th century. Under their rule, Iranian ngineering attained a new peak, although the ction of arch dams was discontinued.

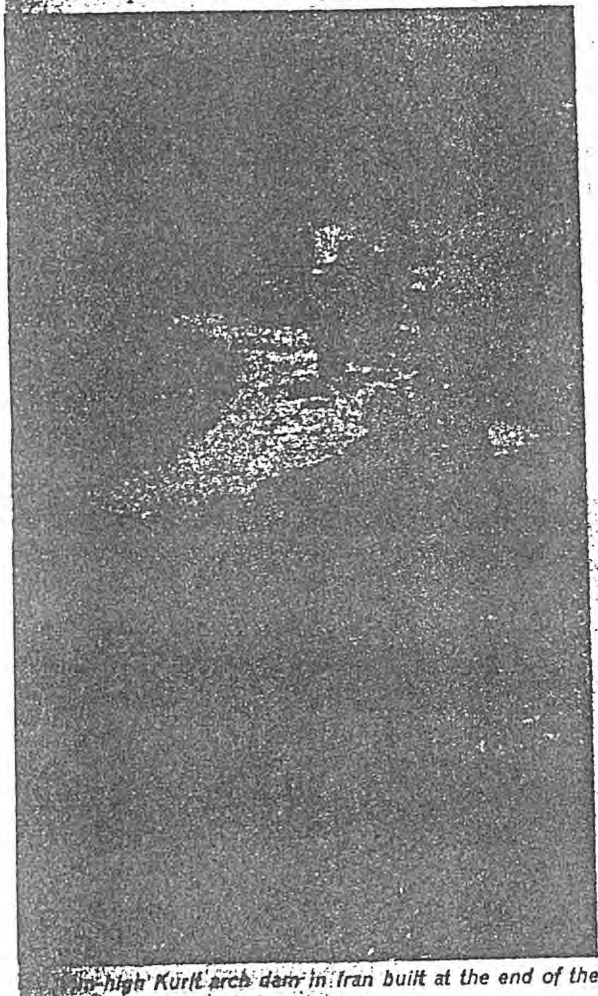
reasons for the short-lived revival of the arch dam t, forgotten since the disruption of the Roman in Iran under the Ilkhans are not known at present. t was imported by the Mongols from China is y, since dams as well as the arch in general have been much used by the Chinese. Quite to the y, in 1274 the Mongols sent the Iranian engineer all Shams-al-Din (1210-1279) as governor to ng in southern China, where he initiated the ction of a dozen dams[8]. That the arch dam concept om the west, with which the Ilkhans maintained atic as well as cultural relations (eg, the Polo s), is equally improbable, as the first of several dams built in southeastern Spain is about one younger. If a transfer of technology ever occurred, therefore have been from east to west by the diary of the Moslem civilization, in which Iran important role at that time.

astern Spain had been settled during the Moslem in the 8th century by Syrians and Yemenites, ught from their arid homelands not only many techniques[9] but already a considerable experience in dam engineering[10]. The Moslem period saw the construction of several low diversion weirs, while the earlier mentioned curved dams were built after the area in question had been reconquered by the Christians[11]. Until about the end of the 15th century this amounted, however, mainly to a political-military takeover, leaving unchanged much of the Moslem infrastructure, especially with respect to irrigation procedures and techniques[9].

The earliest curved dams in southeastern Spain are very sturdy structures, relying for stability mainly on gravity and very little on arch action. The Almansa dam, 80km northwest of Alicante, consists of a 15m high curved portion completed in 1384, to which a 6m high polygonal gravity section was added in 1586. The Tibi dam erected from 1580 to 1594, under the reign of Philip II (1556-1598) and after approval by the famous hydraulician Juanelo Turriano (1500-1585), some 20km north of Alicante is 42m high and exceedingly thick. Both dams were built of rubble masonry set in lime mortar and faced with carefully placed cut stones. Both also show fairly refined hydraulic features. One is the scouring gallery provided through their bases for purging the reservoirs of silt accumulations. In view of this phenomenon the outlet for the irrigation water at Tibi dam was additionally equipped with a vertical intake shaft connected to the reservoir by a multitude of small inlets at various levels, similar to the arrangement used at Kebar and most other Iranian dams since the end of the 13th century.

A true arch dam is the Elche dam (Fig. 3), the construction of which was begun in 1632 some 20km west of Alicante. It consists of a 23m high, cylindrical main arch, which is curved only modestly in relation to its relatively high length-to-height ratio. The upper part of the main arch rests on the right side against an abutment block, an artifice used quite frequently in arch dams, sometimes even on both valley sides. From the abutment block a smaller secondary arch takes off, while on the left side the main arch ends abruptly in front of a narrow gully, a short wing wall closing off the reservoir upstream. The clever utilization of the peculiar topographical features of the site, as well as the satisfactory distribution of the stresses in the main arch (Fig. 4), testifies to the fine structural feeling of its designer(s).

The last mentioned quality is remarkably lacking in the 17th century Relleu dam 30km northeast of Alicante. Located in a narrow gorge, the lowest 7m of which were



...m-high Kurit arch dam in Iran built at the end of the

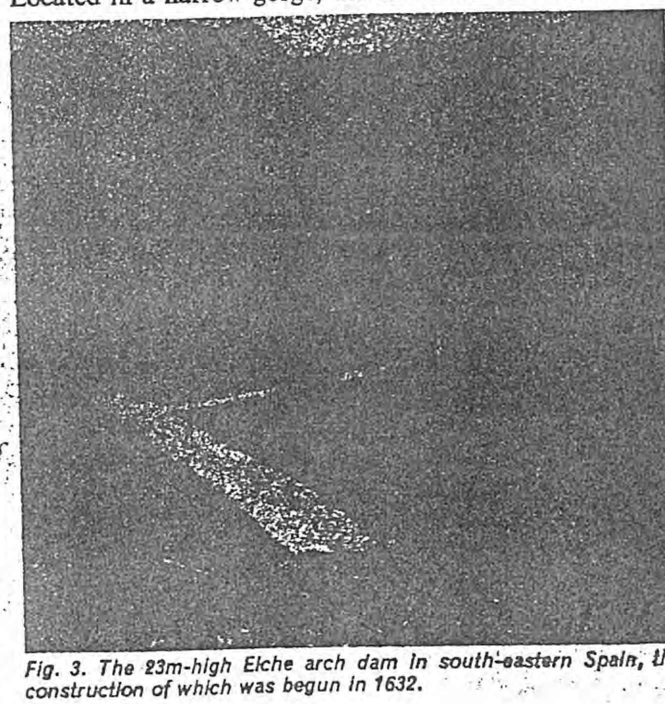


Fig. 3. The 23m-high Elche arch dam in south-eastern Spain, the construction of which was begun in 1632.

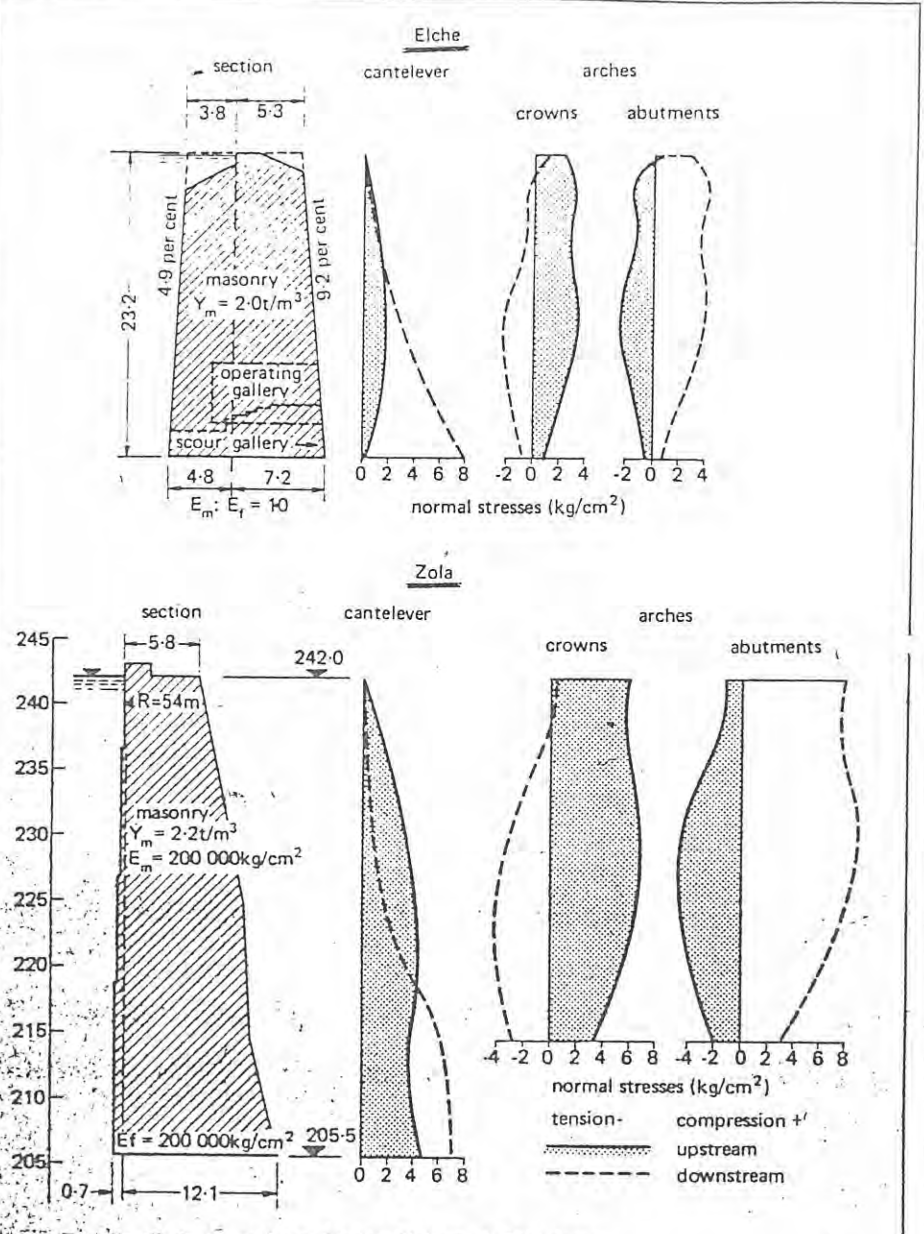


Fig. 4. Results of stress analyses for the Elche and Zola dams derived by the modern "arch and crown-cantilever adjustment" method (contours and dimensions in metres).

barely wide enough to accommodate the scouring gallery, the dam has an almost plane upstream face, while the likewise vertical downstream face is curved only very slightly. Its stability relies therefore not in arch action, but rather in that of a wedged-in triangular plate, the thickness of which is constant in any vertical section. The height of the dam was increased by 5m in 1879, to compensate for the complete silting up of the irrigation reservoir.

After its "degeneration" at Relleu the arch dam concept was abandoned in later Spanish dam construction in favour of buttress, gravity and earth fill structures. The two last mentioned types continued to be used in the old dam building countries like Japan, southern India and Iran, and were also almost exclusively adopted for the dams which began to be built in Turkey, Italy, Austria, Czechoslovakia, Germany, France, Great Britain and the Americas. A notable exception, and again a true arch dam, was the Ponte Alto flood control structure, the building of which was started in 1611 in the extremely narrow canyon of the Fersina near Trento in northern Italy[12]. Originally only 5m high, the dam was raised seven times and in 1887 reached its final height of 39m, over all of which the thickness of the masonry is practically constant. Shortly before the final height increase, the similar Madruzza dam was built downstream to protect the older lower parts of the Ponte Alto dam by creating a backstorage, which on the one hand counteracts the water pressure on them, and on the other, mitigates the shock of the spilled floods on their foundations.

The pioneers

The Ponte Alto dam was probably known at first hand by François Zola (1795-1847)—the father of the famous French writer Emile Zola—for he was born and educated in nearby Venice and in the early 1820s worked on the construction of a railway near Linz in Austria[13]. At that time Austria dominated both Venice and Trento, and the Ponte Alto dam was being raised for the third and fourth times. In 1837, soon after he had established himself as a consulting engineer in Marseilles, France, Zola took part in a competition for a new water-supply scheme for Aix-en-Provence. He proposed an aqueduct from the Infernet creek east of the city, whereby the large seasonal variations of the relatively modest run-off were to be regulated by three consecutive reservoirs. These were all to be formed by arch dams. After a long fight for his ideas, Zola was able to initiate the work on the first of his dams in 1847, but then died just two months later. Deprived of its leader, the work progressed only haltingly and was completed seven years later in 1854.

Named after its designer, the Zola dam is 43m high, modestly curved and fairly sturdy. Also, besides being a very fine structure, still in excellent shape, it has the additional distinction of being the first arch dam designed on the basis of an analysis of the stresses in it. The calculation supposed that the dam consisted of a stack of independent arches, each of which had to resist the total pressure corresponding to its depth below the reservoir water level. The average stress in every arch was determined by the "cylinder formula" as the product of pressure and slenderness*.

Structural statics

This simple relationship had already been found experimentally by the French physicist Edmé Mariotte (1620-1684) and was formulated in 1826 by Louis C. M. Navier (1785-1836), the creator of structural statics, who also laid the foundations for the theory of elastic

* Ratio of radius of curvature of an arch to its thickness.

...ble I—Data on arch dams built up to World war I[1]

...ame	Country	Period of construction	Height (m)	Length (m)	Structural characteristics[2]			
					L'/H	B/H	R/C	Ø
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...ebar	Iran	ca. 1300	26	55	0·8	0·35	6	40
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...bbas	Iran	ca. 1300	20	?	?	?	?	?
...che	Spain	1632–?	23	120	3·0	0·50	7	67
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...worth	Australia	1898	20	134	?	0·33	83	100
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...sis	Italy	1898–1900	38	40	1·0	0·46	?	?
...per Otay	USA (California)	1901	23	86	3·7	0·16	90	60
...rossa	Australia	1899–1903	36	144	4·0	0·29	45	136
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...wley	USA (Oregon)	1908/15[5]	28	49	1·8	0·10	22	181
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...linder	USA (Wyoming)	1905–09	65	132	1·4	0·45	14	72
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[illegible]	Philippines	1912	30	70	2·3	0·13	35	116
[illegible]	USA (California)	1912	24	142	2·9	0·21	16	99
...ek 4	USA (California)	1912–13	24	67	2·8	0·35	?	?
[illegible]	USA (California)	1913	15	45	3·0	0·38	?	60
...Creek	USA (Alaska)	1913–14	51	195	3·8	0·25	55	114
[illegible]	Italy	1313–14	38	81	1·7	0·18	15	158
[illegible]	USA (California)	1913/16/19[5]	84/64[6]	244	2·8	0·46	44	76
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...length of arch, excluding wing walls or artificial abutments, H = maximum height, B = base width, R = radius of crest arch, C = crest width, R/C = slenderness
...central angle of crest arch (degrees)
...heightening by 4m about 1850
...heightening by 5m in 1879
...heightening, to which structural characteristics are referred
...gravity base, to which structural characteristics are referred

...he latter was formalized only in 1854 by Jacques ...ese (1822-1883), like Navier a French teacher ...archer in civil engineering sciences[14]. Notwith... the simple calculation Zola had to employ, the ... his dam are reasonable even when analysed ... to present-day methods (Fig. 6).

... this pioneering example, it was almost 80 years ... next French arch dam of similar size was built ...omme river in the Massif Central. In part this ...resulted from the fact that the earliest descrip... Zola dam appeared only in 1872 and in another ... while the deserved wide publicity was given to ... first standard work on *The Design and Con... Dams*, published in 1888 by the Swiss-American ...engineer Edward Wegmann (1850-1935).

...eantime the design of gravity dams had been ... rational basis, which resulted in a preference ...pe of structure during the following half century. ...them were given a slight curvature in plan as ...ted by the French engineers Auguste M. I. ...-1884) and Emile F. X. P. Delocre (1828-... fundamental papers on the design of masonry ... they published in 1866 and in which they ... all the old Spanish structures but not the Zola dam[16]. In his paper, Delocre even outlined a method of analysis for arched dams very similar to that used by Zola, whereby he admitted a maximum permissible stress of 0·6MN/m², ie, less than 10 per cent of what is generally allowed today[17]. In an analogous study in 1879 Albert G. Pelletreau (1843-1900)[18] found that to minimize the volume of an arch dam its radius of curvature should decrease from crest to base, which according to the "cylinder formula" also yields smaller arch thicknesses for a given allowable stress.

No publicity at all was received by the small but remarkable Jones Falls dam (Fig. 5), built from 1828 to 1831 in the virgin forests of Canada for a barge canal from Ottawa to Kingston on Lake Ontario[19]. The structure is 19m high, strongly curved and shows almost the same, considerable thickness from crest to base. Especially noteworthy are its unprecedentedly high length-to-height ratio and the fact that the masonry blocks were set in vertical, instead of the usual horizontal, courses. Also unusual is the clay fill placed against the upstream face as an additional water barrier. The dam, as well as the whole canal, was designed and its execution directed by Lieutenant-Colonel John By (1779-1836) of the British Army engineering corps, who was recalled from retirement

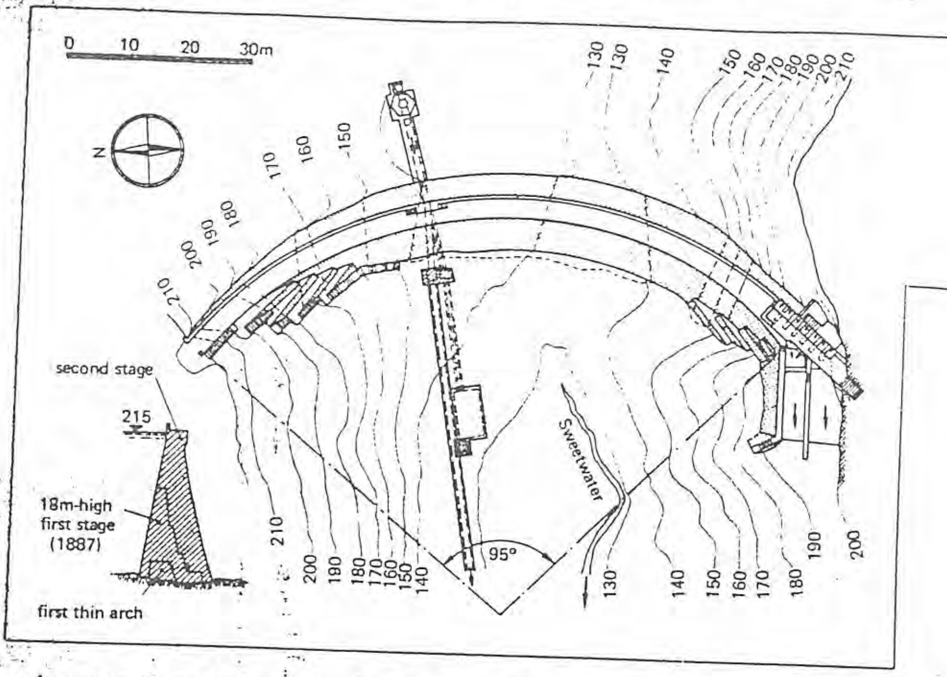


Fig. 6. Plan and median section of the 30m-high Sweetwater arch dam completed in 1888 south-east of San Diego, California (contours in feet).

and sent to Canada for the task. Besides the Jones Falls dam, he built also several low curved weirs like the one constructed by the great English engineer John Smeaton (1724-1792) on the Coquet river north of Newcastle-upon-Tyne in England. Although the curvature of these weirs served to increase the discharge of the overflowing water, they might have inspired By to use the arching effect to strengthen the Jones Falls dam. A similar structure which he had built on a straight alignment at the Hog's Back in Ottawa had failed early in 1829.

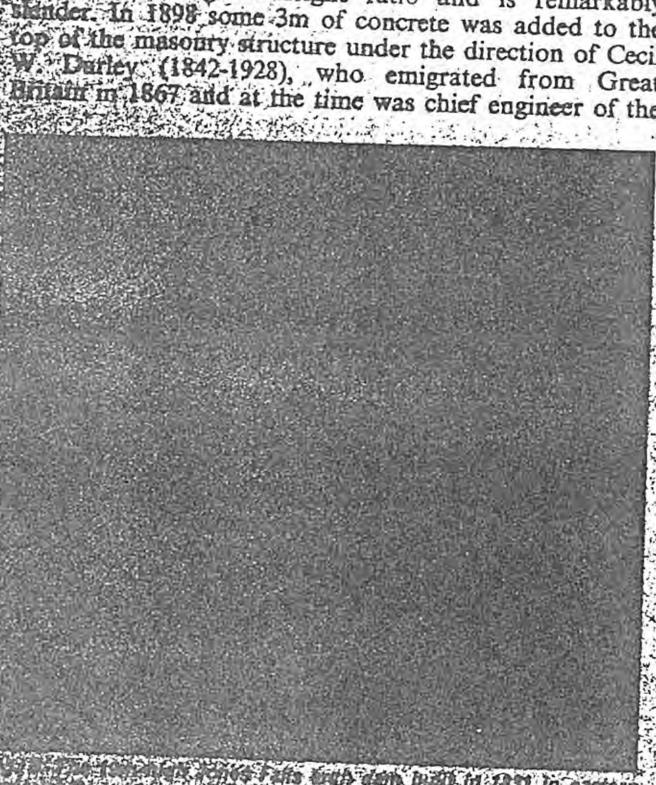
At the other end of the British empire a small arch dam was built in 1855/56 near Parramatta east of Sydney Australia[20]. It was designed by Captain Percy Simpson (1787-1877), who had come to Australia in 1822 as commandant of a convict settlement and later became surveyor and land commissioner. The dam shows a considerable length-to-height ratio and is remarkably slender. In 1898 some 3m of concrete was added to the top of the masonry structure under the direction of Cecil W. Darley (1842-1928), who emigrated from Great Britain in 1867 and at the time was chief engineer of the Public Works Department of New South Wales. Concurrently he initiated the construction of a whole series of very thin arch dams in the Blue Mountains behind Sydney to provide small water-supply reservoirs in the newly settled arid areas[21]. These dams all had one vertical cylindrical face, were of moderate height (the highest was the Lithgow No. 2) and were the first arch dams to be built entirely of concrete*, which was batched by volume, hand mixed, transported in wheel barrows, placed in thin layers and consolidated by tamping. It contained roughly 280kg/m^3 of cement, but reached only about one quarter of the strength attainable today with a similar mix. This was sufficient to cover the average stresses of up to 2·6MN/m^2 calculated still with the "cylinder formula" for independent arches, but left a narrow safety margin with respect to some local stress concentrations resulting from the boldness of the dams' design. The most daring is the Mudgee dam which is very thin notwithstanding its extreme length-to-height ratio[22].

When Darley started the construction of his arch dams he could rely not only on the example set by the Parramatta dam, but also on that of an even bolder structure in California publicized by Wegmann's earlier-mentioned book. This was the (Big) Bear Valley dam built in 1883/84 at over 2000m above sea level in the San Bernardino mountains some 130km east of Los Angeles to the design of the young engineer and land developer Frank E. Brown (1856-1914). Although only moderately curved, it set a record of slenderness. It performed quite satisfactorily but was replaced in 1911, because of fears raised by the considerable volume of its irrigation reservoir of almost 50m^3 × 10^6, by a more conservatively designed buttress dam of the multiple arch type.

Southeast of San Diego the quite similar Upper Otay dam is, however, still in operation. Slightly north of it, the Sweetwater dam had also been started as a thin cylindrical arch, but was changed to a far sturdier structure when the later renowned consulting engineer James D. Schuyler (1848-1912) took over the direction of the works[23]. In contrast to its forerunners the upstream face of the Sweetwater dam is not vertical, having instead a slope similar to the downstream side, so that in place of the upstream face radii of curvature, those of the arch axes are constant from crest to base (Fig. 6). The overall construction costs of the dam amounted to some $15 a cubic metre. When an inflation factor of about six is taken into account, this corresponds almost to present day costs for a similar structure. A short time after its completion the Sweetwater dam successfully withstood almost two days of overtopping by a flood, thus testifying to the inherent strength of a well-built arch dam.

The breakthrough

The Sweetwater dam served as a model for, among others,



…Jones Falls arch dam built in 1831 in eastern…

* Although concrete had already been used in some Roman dams, its modern form based on Portland cement was introduced into dam engineering in 1866 at the Boyds Corner gravity dam 80km north of New York, USA.

...inder and Buffalo Bill (formerly Shoshone) dams ...al and northwestern Wyoming, USA. Built by ...tly formed Bureau of Reclamation of the United Department of the Interior from 1905 to 1910 these reached the unprecedented heights of 65 and 99m ...ively. Accordingly they also required considerable ...ies of construction materials, ie 50 000m³ of ...ry for the Pathfinder and 63 000m³ of concrete for ...ffalo Bill dam. Even more remarkable than their ...ions, however, is the fact that they were the first ...ms, which were not designed merely as a stack of ...al arches[24]. Their interdependence was taken into ... by considering also the median vertical section ...m which is statically a cantilever fixed at the base. ...ter and other external loads were then divided in ...ly and horizontally carried parts by adjusting the ...al deformations of the median cantilever to the ...flections of the arch crowns. The latter were ...ed according to the theory of elastic arches. This ...nally became generally accepted, although it still ...ed imperfections and considered the arches as fixed at the abutments[25].

...distribution of the loads resulted in a considerable ...or the lower arches, while the upper ones had to ... partially the cantilever. The new method of ... had been developed in the late 1880s by Hubert ... and Luther Wagoner (1847-1922) for checking ...s in the Bear Valley and Sweetwater dams, but ...ished in a local journal and thus escaped general ...[26]. The latter was achieved only after the pub... of the method in 1904 by Silas H. Woodard ...1)[27], who had formulated it anew while designing ...man curved gravity dam 60km south of Denver, ... which incidentally is also the headquarters of ...reau of Reclamation.

...discussion of Woodard's paper, Gardner S. ... (1866-1931), then professor of hydraulic engin... the Cornell University in Ithaca, New York, ...the suggestion of the French engineer Pelletreau ... the radius of curvature of an arch dam from ... Besides the advantages already evident from ...inder formula", the theory of elastic arches now ...t that the new design would improve the stress ...ion within the lower arches, since the shorter ...ed larger central angles. In contrast to the ...al or constant-radius layout used until then, the ...m was therefore named "constant-angle" arch ... its patentee and first applier Lars R. Jorgensen ...)[28]. A native of Denmark holding German ... mechanical and electrical engineering, Jorgensen ...rated to America in 1901, where he worked as a ...ic engineer in California and founded his own ... firm in San Francisco in 1914.

...same year, Jorgensen's first constant-angle or ...radius arch dam was completed for a hydro ... on the Salmon Creek near Juneau in south... Alaska. Although its median vertical section ... that of the Sweetwater, Pathfinder and Buffalo ..., the shape of the Salmon Creek dam is strictly ...sequence of the new layout and has become ... for the variable-radius type of arch dam. The ... bulging serves to off-set the undercutting by the ...curved lower arches near the abutments while the ...ed downstream toe reduces the tensile stresses ... upstream heel. The full realization of the new ...was made possible by building the dam completely ...crete, of which a total of 40 000m³ were required ...hich contained 280kg/m³ of cement. From the ... processing and the mixing plants near the ... heel of the dam, the concrete was lifted to the ... temporary steel tower, then chuted into the ... Fig. 7.

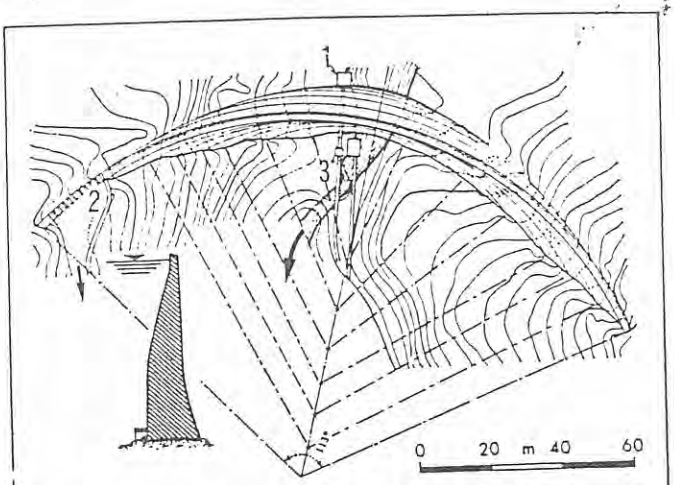


Fig. 7. Plan and section of the Salmon Creek variable-radius arch dam near Juneau, Alaska. Built by Jorgensen in 1914 it became the standard design for this kind of dam. The intake is indicated by the figure 1, the spillway by figure 2 and the valve by figure 3.

To allow for the contraction of the concrete when the heat produced during its set cools off, the Salmon Creek dam was subdivided into three construction blocks by two vertical joints—a further innovation in arch dam engineering. At the Lake Spaulding dam, 110km east of Sacramento, California, which had been begun as a curved gravity dam but whose upper three quarters were continued from 1913 on as a variable-radius arch dam, the contraction joints were provided with keys and filled with grout injected through drill-holes[28]. In later dams special grouting pipes and outlets were embedded in or next to the joints, the spacing of which was moreover reduced to about one quarter of the 50 to 70m used at the Salmon Creek dam.

The technical, as well as economic, advantages of Jorgensen's design were immediately recognized, and it became rapidly very popular in the west of the United States and elsewhere. In this it received additional impetus from the quickening pace in the development of hydroelectric power resources. The variable-radius arch dam was to prove especially suitable for high and large structures, although it never replaced the cylindrical type completely. Scandinavian designers, the Bureau of Reclamation, as well as the French engineers persisted for a long time in the use of the cylindrical design even for large structures.

The Jorgensen type of arch dam was introduced in Europe a few years after its first use by Heinrich E. Gruner (1873-1947). He had inherited a renowned consulting firm in Basle, Switzerland, and had closely followed the developments in America ever since his stay there in 1900/01. In 1917 he was commissioned to design the Montsalvens power dam 20km south of Fribourg, Switzerland. Completed in 1920 the structure is 55m high, strongly curved and relatively sturdy (Fig. 8). Its horizontal sections are not circular but follow the funicular curves for the part of the water load supported by them. Moreover, the arch thickness increases from the crown towards the abutments to take care of the stress concentrations near the latter.

The two innovations resulted from the use of a considerably improved method of analysis published in 1913 by Hugo F. L. Ritter (1883-1956), a son of Wilhelm Ritter (1847-1906), the well-known professor for statics at the institute of technology in Riga, Latvia, and Zurich, Switzerland[29]. Ritter (Jnr) had undertaken a study tour through the United States in 1909/10 and was familiar with Woodard's work. His method was refined by Gruner's

collaborators Alfred Stucky (1892-1969) and Henri Gicot (b. 1897), who later became the two most prominent Swiss arch dam designers. In the improved analysis, the radial deflections of the arches were adjusted to those of the median vertical section as well as some additional cantilevers on both sides. This permitted the determination of the variations in the distribution of the loads acting on the dam both in the vertical and in the horizontal sense[30].

Ritter's method of analysis was further expanded between 1923 and 1935 at the Bureau of Reclamation under the direction of John L. Savage (1879-1967), its chief design engineer for over 20 years. The principal additions were the adjustment of the tangential deflections and the rotations in horizontal planes, as well as taking into account of the deformations in the foundation rock. Instead of solving the many linear equations tying the load distribution on arches and cantilevers to the adjustment of their deformations, it was at that time quicker to seek the proper load distribution by trial and error.

The procedure, which was supplemented by a large body of auxiliary tables, was therefore aptly named "Trial Load Method"[31]. After adaptation to electronic data processing and many additional refinements the method remains the one most frequently used. However, it still represents only an approximation of the theory of thick shells, which arch dams actually are. The many attempts since the early 1920s to directly use the latter theory stumbled more often than not over the practical difficulties of its application. These are being overcome only now with the introduction of the analysis by small finite elements and the availability of computers having sufficient storage capacity and speed.

Parallel to these theoretical developments, great efforts were made to collect pertinent data from structures under construction or already in operation. The first measurements of the deflections of an arch dam under load appear to have been those at the 12m high thin arch dam on the Barren Jack Creek in New South Wales, Australia, in 1908/09[22]. They were carried out from scaffolding on the downstream face, while at the Salmon Creek dam surveying methods were introduced for the purpose, which were perfected at the Montsalvens dam and later structures. Montsalvens was also the first arch dam to be equipped with permanent instruments. in this case electric resistance thermometers embedded in the concrete and connected by cables to the measuring stations*. On the initiative of Fred A. Noetzli (1887-1933), a Swiss engineer who emigrated to America in 1915 and became one of the foremost dam designers in the western United States, an 18m-high cylindrical arch dam was built in 1926 on the Stevenson Creek, 65km northeast of Fresno, California, for the sole purpose of studying its behaviour under closely controlled loading conditions[32].

The measurements on the Stevenson Creek experimental dam were checked by testing 1/40 and 1/12 scale models of it at the Universities of Princeton, New Jersey, and Boulder, Colorado, respectively[32]. The first model consisted of celluloid, while the second was built of a concrete similar to the one used for the prototype. In both tests the water load was simulated with a thin layer of mercury to obtain exaggerated and hence measurable deformations and strains, from which the stresses could be calculated.

Although two-dimensional models of gravity dams had been tested already at the beginning of the century, the use of this technique in arch dam engineering constituted an innovation which proved highly beneficial. Today the method has evolved along two distinct lines, represented by the two laboratories which are the most prominent in the field. One is the Laboratorio Nacional de Engenharia Civil set up in 1946 in Lisbon, Portugal, which uses small celite-plaster models loaded with mercury. By contrast the other, the Instituto Sperimentale Modelli e Strutture

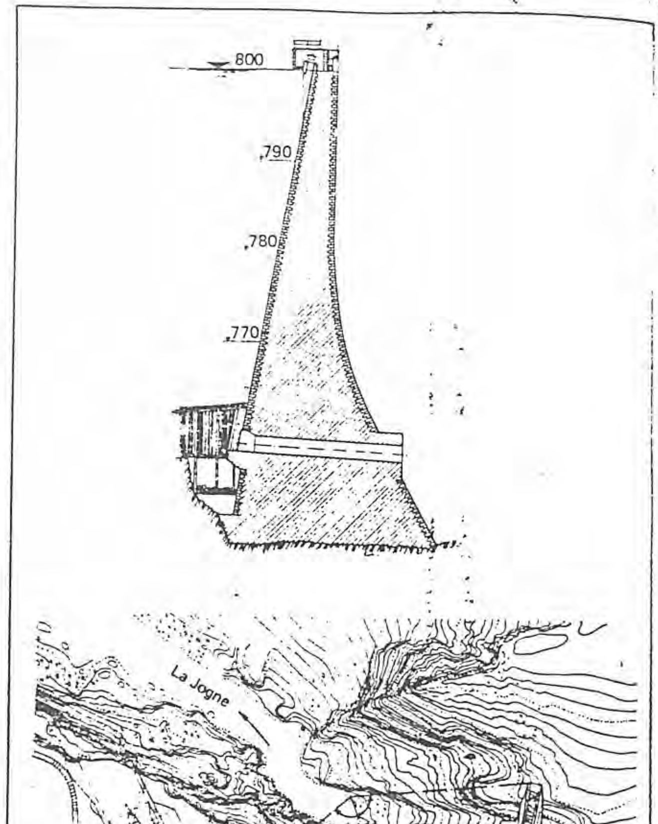


Fig. 8. Plan and median section of the 55m-high Montsalvens dam completed in 1920 south of Fribourg, Switzerland.

founded in 1951 in Bergamo, Italy, prefers relatively large pumice-concrete models, to which the loads are applied by hydraulic jacks.

Involuntary "tests" of sorts were finally provided late in 1925 and early in 1926 by the 16m-high Moyie arch dam in northern Idaho and by the 19m-high Lake Lanier arch dam in western North Carolina, both of which lost their right abutment over more than two thirds of their height without collapsing[33]. These first failures of arch dams thus attested once more to the great strength reserves inherent in this type of structure.

(To be continued)

* The first deformation measurements on any type of dam were undertaken on the Eschbach curved gravity dam completed in 1891 near Remscheid in the Ruhr, Germany, while the earliest temperature measurements occurred at the Boonton gravity dam built in 1903 in northeastern New Jersey.

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The Medlow Dam, New South Wales.

The Construction Shows the Thinnest Profile in the World.

By Percy Allan, M.Inst.C.E., M.Am.Soc.C.E.*

The Medlow dam, on account of its slender profile is one of the most remarkable in the world, and is but a sheet of concrete in a sandstone gorge on Adams Creek, in the Blue Mountains of New South Wales. The wall, with a vertical upstream face, is built on a curve of 60 ft. radius, and is 65 ft. high from the foundation to the top of the parapet. The wall has a base width of only 8.96 ft., tapering on the downstream face to 3 ft. 6 in. at a height of 29 ft., thence 3 ft. 6 in. to top water level, finishing with a parapet wall 1 ft. thick for the remaining 3 ft. of height.

freeboard. Thus at Medlow the provision of a 2 ft. 6 in. pathway for traffic across the dam decided the 3 ft. 6 in. thickness, whilst calculation showed that with a flood occurring on top of a full reservoir the water would be running 2 ft. deep through

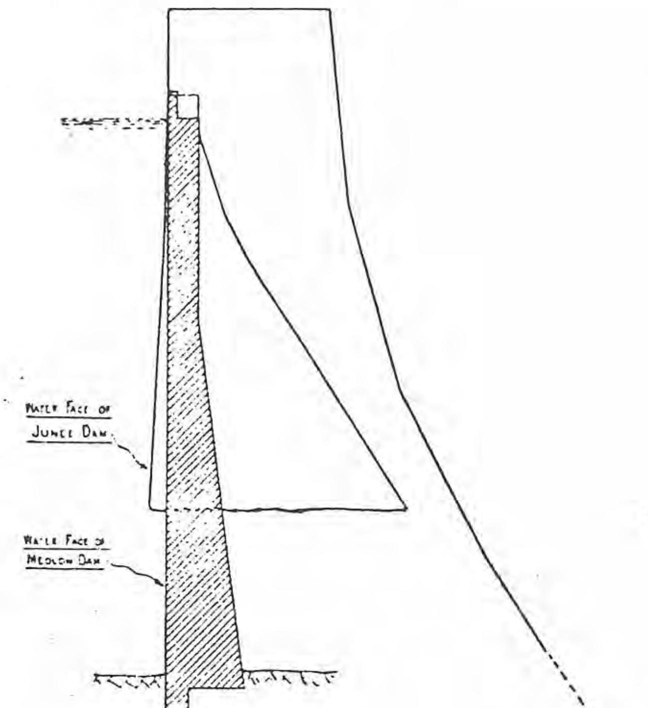


Fig. 1.—Comparative profiles of Medlow, Junee and Burrinjuck dams.

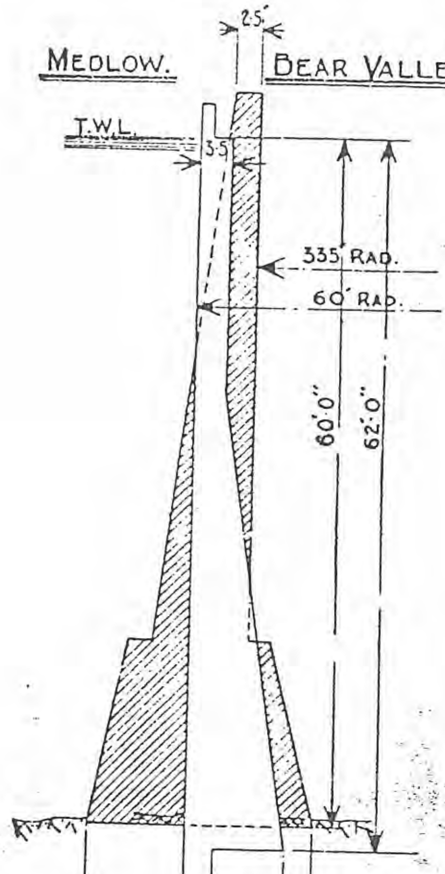


Fig. 2.—Comparison of profiles.

The profile of the gravity dam at Junee, illustrated in Fig. 1. shows at a glance the great saving in material effected by adopting a curved dam in a site so exceptionally suitable as at Medlow.

Whilst the water pressure at the overflow level is, of course, height for height the same in the 3 dams shown in Fig. 1, yet practical considerations really determine the top thickness and required

the spillway, and with practically no fetch to cause waves, a freeboard of 1 ft. was considered sufficient, thus giving a parapet wall 3 ft. above the overflow level.

In the case of Burrinjuck, however, a flood of the big Murrumbidgee River on top of a full reservoir with big waves from a long fetch has to be taken care of, which, with the provision for traffic across the dam, no doubt accounts for the freeboard and the thickness of the wall adopted.

* Public Works Department, Sydney.

Although the old Bear Valley dam, built in California in 1884, and superseded in 1911 by a multiple arch dam, has in the past been referred to as having the thinnest profile in the world, yet a dam built on Crowley Creek, in America, in the same year as Medlow Dam has a thinner profile, whilst Fig. 2 shows the profile of the Medlow dam to also be thinner. The Medlow wall, however, is —due to the narrow gorge—built on a very much smaller radius, viz., 60 ft. as against 335 ft., the maximum pressure on the concrete being only 12 tons per square ft., as against 53 tons per square ft. on the granite voussoirs in the old Bear Valley dam.

In determining the profile of the Medlow dam, the wall was treated as a section of a rigid cylinder, subject to external water pressure, any assistance due to the weight of the wall being disregarded.

The formula used was:—$T. = \frac{RP}{S}$

where T denoted the thickness of wall at any level in feet,

where R denoted the radius in feet,

where P denoted the water pressure in tons per sq. ft., and

where S denoted the stress in tons per sq. ft.

The limiting pressure adopted for the concrete was 12 tons per sq. ft., whilst the highest water surface was taken as within 1 ft. of the top of the parapet wall, or 2 ft. above the overflow of spillway.

$$T = \frac{62.5 \times 62}{2240} = 1.73 \text{ tons}$$

$$T = \frac{60\text{-ft.} \times 1.73 \text{ tons}}{12} = 8.65 \text{ feet}$$

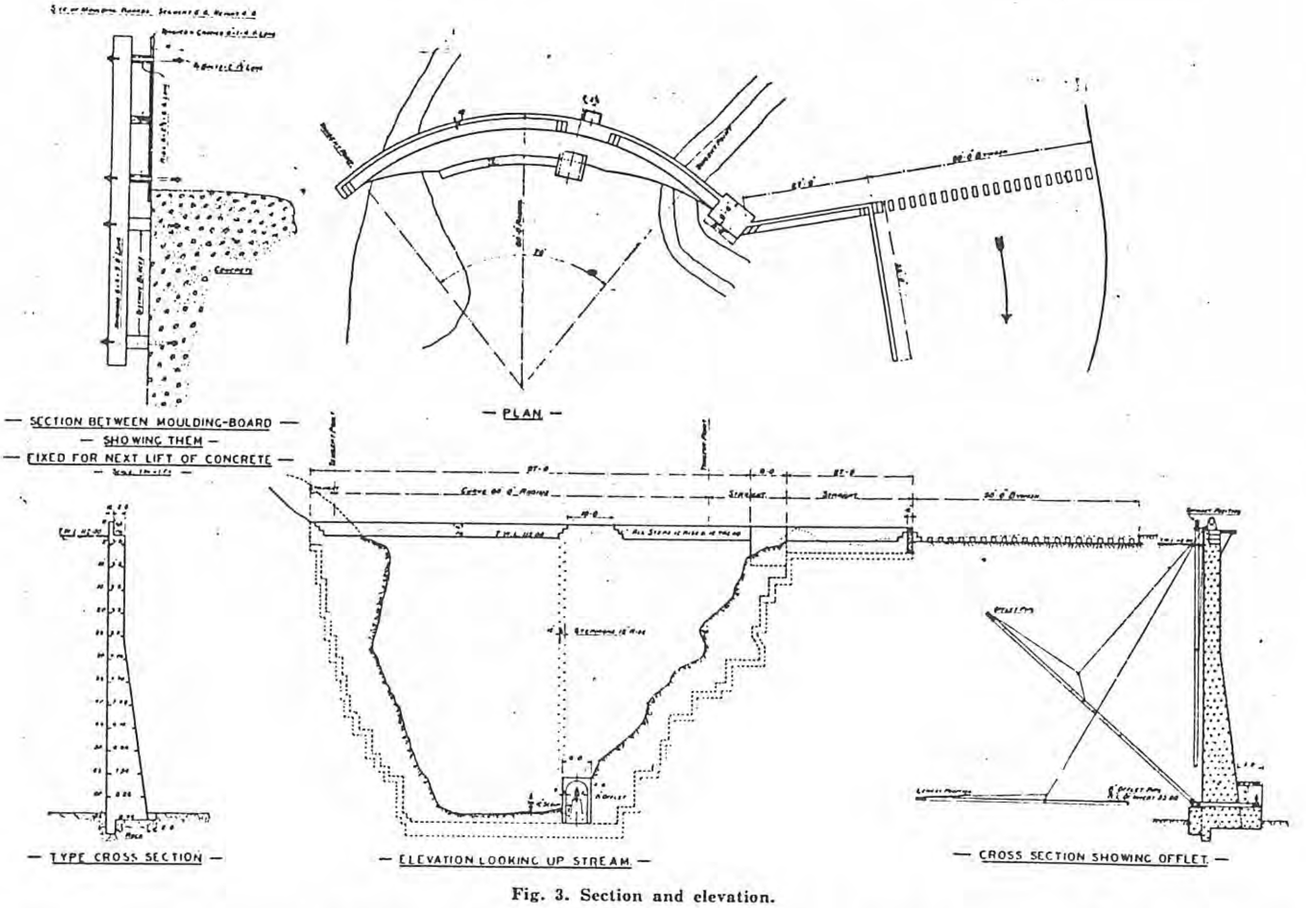


Fig. 3. Section and elevation.

The dam is built of concrete without any reinforcement or "plums." The concrete was composed of 13 cubic ft. of ironstone 2 in. gauge and 8 2/3 cubic ft. of $\frac{3}{4}$ in. screenings, to 1$\frac{2}{3}$ cubic ft. of sand, to 375 lbs. of cement.

With a view to determining the crushing strength of the concrete as under actual conditions in the work, samples were taken from time to time off the banker board, just as the concrete was being placed in the work, and were then made into 6 in. cube blocks. The seven blocks tested showed at two months a crushing strength of 93

tons per sq. ft., and at three months from 93 tons up to 116 tons per sq. ft.—the limit of the machine. One block, however, at 35 days also beat the machine at 116 tons per sq. ft.

Good close sandstone was met with in the foundation trenches, but on either side considerably more excavation had to be taken out than was anticipated in the office plans, as fissures and large bands of iron stone running in all directions had to be contended with.

Along the front line of trench, at intervals of 6 ft., holes, reaching to the bottom of foundation, were left in the concrete, whilst chases were cut in the different benches in each cliff. After the concrete had thoroughly set, iron pipes were temporarily cemented in the holes and chases; cement grout under pressure was then forced down the pipes with a view to filling any spaces between the rock face and concrete.

The whole of the concrete was mixed by hand, on a platform located at the top of the southern cliff, and delivered thence into a hopper provided with a long timber chute reaching to the bottom of the foundation, or such position on the wall as required.

Fig. 3 shows various sections, etc., of the dam; Fig. 4 illustrates the upstream face of the dam and profile boards, and Fig. 5 shows the finished dam.

To provide a supply of water for concrete, two small tanks with earthen bag wall dams were excavated at a level to command the mixing platform, the water being raised from the creek bed by means of a No. 7 Danks' hydraulic ram. To obtain the necessary head of 12 ft. for working the ram, a timber dam faced with a clay bank was built some little distance upstream of the site; thence along the bed of the creek was laid the drive pipe of artesian bore casing, some 480 ft. long by 4 in. outside diameter. The delivery pipe was 1½ in. inside diameter and 335 ft. long. The ram discharged into the upper tank against a head of 130 ft. exclusive of friction. Under these conditions, the ram discharged 54 gallons per hour. Both tanks were filled before starting the concreting, and with a continuous supply of 54 gallons per hour, no shortage of water was experienced in working the 48 hours a week. A batch of concrete was usually found to require 35 gallons of water.

The vertical timbers supporting the profile boarding were of 6 in. x 4 in. hardwood, blocked off the concrete and connected thereto each with two ⅞ in. bolts, with nuts at each end, built 10 in. into the concrete. The bolts were oiled and no difficulty was experienced in unscrewing them from the nuts, which were left in the concrete, the hole being then washed out and plugged with cement mortar.

The lagging was of dressed T. and G. oregon, 1 in. thick, nailed to 6 in. x 2½ in. dressed oregon horizontal ribs cut to radius, the segments being 4 ft. 6 in. deep and in 6 ft. 6 in. lengths. The face of the lagging was coated with soft soap immediately before the concrete was placed in position, the concrete being allowed to set for 48 hours before the profile boarding was removed; the concrete face was then given a coat of cement wash.

A natural depression on one side of the gorge was fashioned into a spillway, discharging some

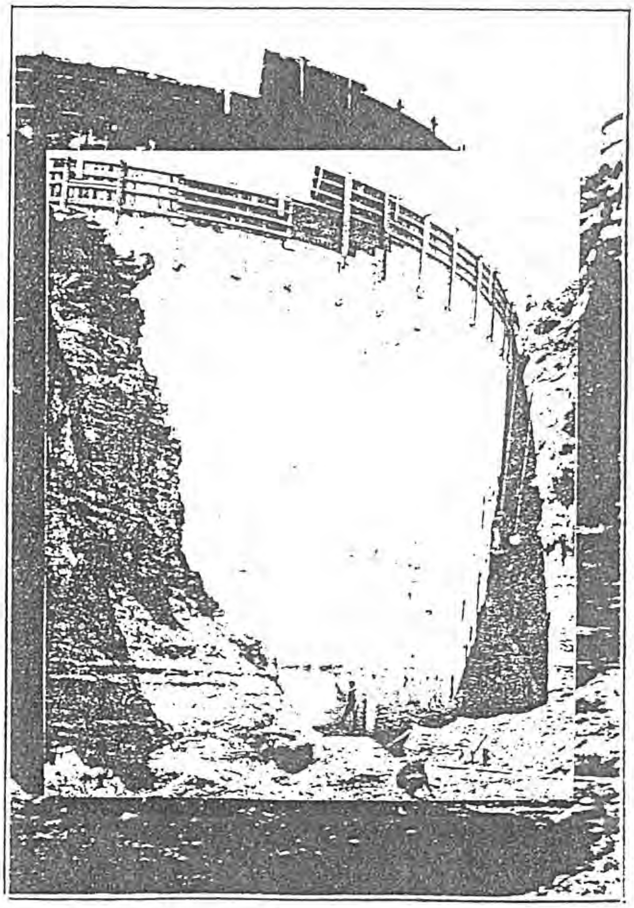


Fig. 4.—Showing upstream and face of dam and profile boards..

little distance downstream of the dam, whilst the parapet wall of the dam itself, 3 ft. above the overflow level of spillway, ensures the whole of the flood waters being passed into the creek without over-topping the dam—a matter of first consideration, with a thin wall without a water cushion at base.

The catchment area is 1150 acres, with an average rainfall of 39 in., the dam holding up a lake 0.62 miles long with a water surface of 12 acres, containing 67 million gallons of very good water. The trees, stumps, scrub, and under-

growth were cleared from the site of the reservoir and the whole surface left bare to half a chain beyond the top water level, so that on the reservoir filling no trouble was met with from discoloration or decaying vegetable matter.

The work was completed in December, 1907, and although water was stored to within 19 ft. of top water level in the following February, it was not until July, 1908, that the spillway overflowed. The wall was then reported as weeping at several of the ladder rungs and at two pin holes at the 8ft. level, whilst a further weep was reported near the top water level which, upon enquiry, was found to have resulted from the upsetting of a bucket of soft soap, which was not washed off before the placing of the next batch of concrete. Whilst an efflorescent or deposit of lime brought out of the cement with the usual sweating is noticeable on the wall, yet the weeps have now taken up, the wall being dry with the exception of some damp patches at one or two places.

The dam was designed in the public works department of New South Wales, under the direction of the late Mr. L. A. B. Wade, M.Inst.C.E., then chief engineer for irrigation and drainage, the work being built by day labour under the supervision of Mr. Percy Allan, M.Inst.C.E., M.Am.Soc. C.E., then principal assistant engineer for water conservation. The work cost £2762, exclusive of expense involved in clearing the site of the reservoir, costs of preliminary investigation, survey, supervision and engineering expenses.

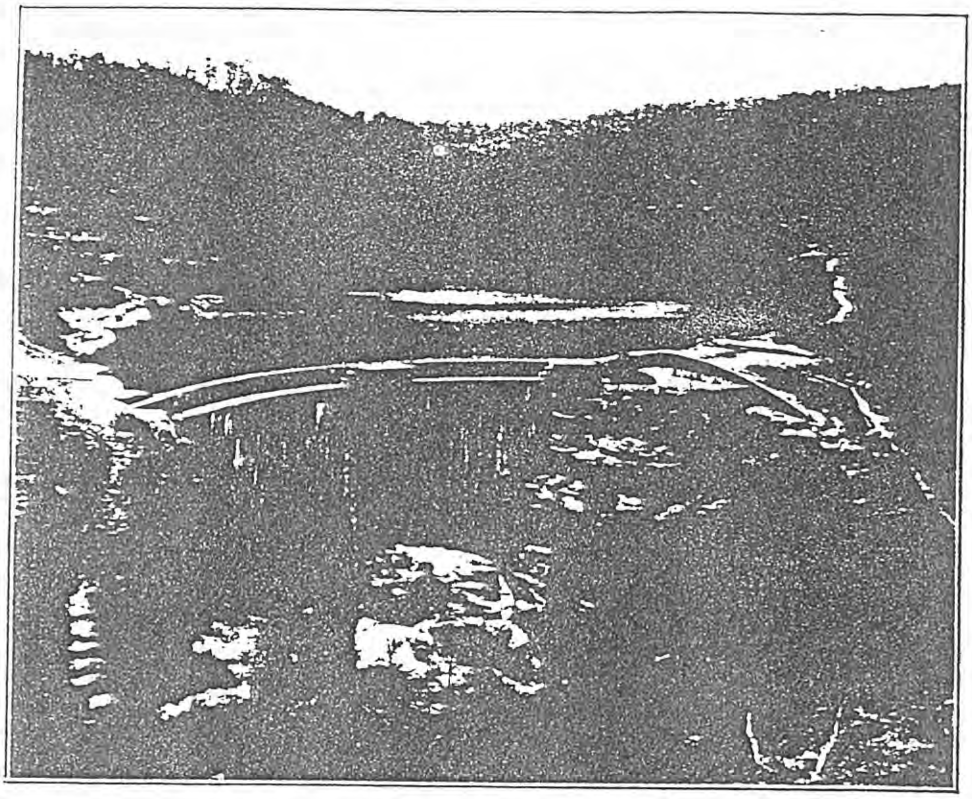


Fig. 5.—The Finished Dam.

The proposal of Mr. E. M. de Burgh, engineer-in-chief for water supply, N.S.W., to erect a dam on the Cordeaux river for the storage of water necessary for the maintenance of Sydney's supply, was laid before the parliamentary standing committee on public works last month. The scheme is to erect the dam immediately below the junction of the Cordeaux creek, to impound a further storage of 15,858,490,000 gallons of water. The dam is to be constructed of cyclopean concrete, 160 feet high from bed of the river, and 1525 feet long at crest, involving the use of 177,396 cubic yards of concrete. The storage will cover an area of 1603 acres; the full supply level will be 985.93 ft. standard datum. The cost is estimated at £490,000.

THE MEDLOW DAM.

THOUGH it has been completed for some years now, no description of the Medlow Dam, which, on account of its slender profile, is one of the most remarkable in the world, has hitherto been published in this country. The dam, which is but a sheet of concrete, is situated in a sandstone gorge on Adams Creek in the Blue Mountains of New South Wales. The wall, which has a vertical upstream face, is built on a curve of 60ft. radius, and is 65ft. high from foundation to the top of the parapet wall—see Fig. 1, which gives a plan and an elevation of the dam looking upstream. It has a base width of only 8.96ft., and it tapers on the downstream face to 3ft. 6in. at a height of 29ft., and from thence to top-water level it is the same thickness, and finally finishes with a parapet wall 1ft. thick for the remaining 3ft. of height—see Fig. 4.

In determining the profile, the wall was treated as a section of a rigid cylinder, subject to external water pressure, any assistance due to the weight of the wall being disregarded.* The formula used was

$$T = \frac{R\,P}{S}$$

where T denotes the thickness of wall at any level in feet,

R ,, radius in feet,

P ,, water pressure in tons per square foot, and

S ,, stress in tons per square foot.

The limiting pressure adopted for the concrete was 12 tons per square foot, whilst the highest water surface was taken as within 1ft. of the top of the parapet wall, or 2ft. above the overflow level of spillway. Hence

$$P = \frac{62.5 \times 62}{2240} = 1.73 \text{ tons.}$$

$$T = \frac{60\text{ft.} \times 1.73 \text{ tons}}{12} = 8.65\text{ft.}$$

Fig. 4 also gives a comparison of the profile of the old Bear Valley Dam, California, built in 1884, but replaced in 1911, and the Medlow Dam built in 1907. The former was generally regarded as an example of very bold proportioning in design, and has been referred to in text-books as having probably the thinnest profile ever adopted in such a structure.† The Medlow profile, however, is thinner, but the wall being built on a very much smaller radius, namely, 60ft., as against 335ft., the maximum pressure on the concrete is only 12 tons per square foot, as against 53 tons per square foot on the granite voussoirs in the old Bear Valley Dam.

The Medlow Dam is built of concrete without reinforcement or "plums." The concrete was composed of 13 cubic feet of ironstone broken to a 2in. gauge, 8¾ cubic feet of ⅝in. basalt screenings, 13 cubic feet of river sand and 375 lb. of cement. The method adopted in measuring and mixing the materials was as follows: A gauge box with a capacity of 13 cubic feet was first placed on the concrete board and filled with the ironstone, which was then spread out 6in. deep. The box for screenings with a capacity of 8¾ cubic feet was then placed on top of the spread ironstone and filled with screenings, the latter being then spread over the ironstone. The sand box with a capacity of 13 cubic feet, after being placed on the cement board, was filled with sand, which was then spread out 6in. deep, the cement being then spread over the sand; the cement and sand being afterwards turned over three times in a dry state. The cement and sand, after being thoroughly mixed as described, were then spread over the screenings and ironstone, and the whole turned over in a dry state three times, water being added on the fourth turn, the mixture being then turned again twice in a wet state.

From actual measurement it was found that on the average there were 6.74 cubic feet of voids in 13 cubic feet of the 2in. ironstone, and 3.52 cubic feet in 8¾ cubic feet of ⅝in. screenings, and that the materials made in bulk, when measured in a gauge box, [illegible] cubic feet of concrete.

With a view to determining the crushing strength of the concrete as under actual conditions, samples were taken from time to time off the banker boards just as the concrete was being placed in the wall, and were then made into 6in. cube blocks. The seven blocks tested showed at two months a crushing strength of 93 tons per square foot, and at three months from 93 tons up to 116 tons per square foot, the limit of the machine. One block, however, at thirty-five days, also beat the machine at 116 tons per square foot. The whole of the concrete was mixed by hand, on a platform at the top of the southern cliff—which platform may be seen at the right top corner of the bottom view given on page [illegible]—and delivered thence into a hopper provided with a long timber chute reaching to the bottom of the foundation or such position on the wall as was required.

To provide a supply of water for concrete, two small tanks with earthen bag wall dams were excavated at a level to command the mixing platform, and water was raised into them from the creek bed by means of a No. 7 Danks hydraulic ram. In order to obtain the necessary head of 12ft. for working the ram, a timber dam faced with a clay bank was built some little distance upstream of the site. A view of this dam is given in Fig. 2. From it there was laid along the bed of the creek the drive pipe of artesian bore casing, some 480ft. long by 4in. outside diameter. The delivery pipe from the ram—which can be seen running up the right-hand cliff in Fig. 3, being

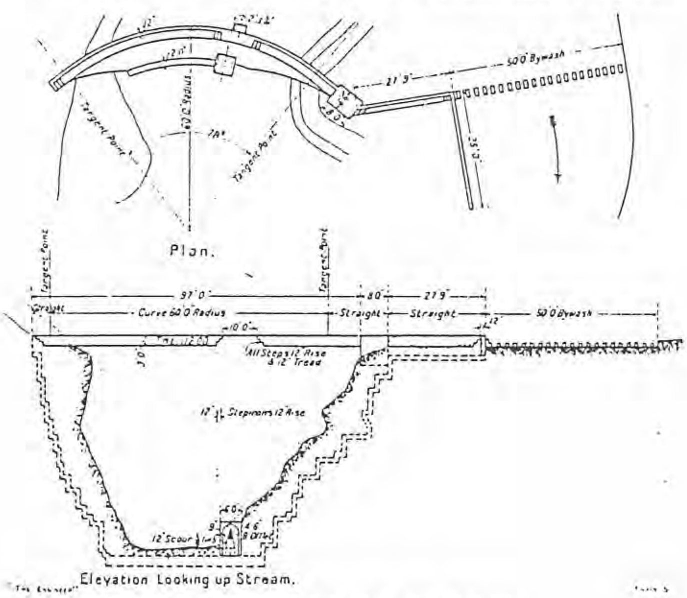


Fig. 1—THE MEDLOW DAM PLAN AND ELEVATION

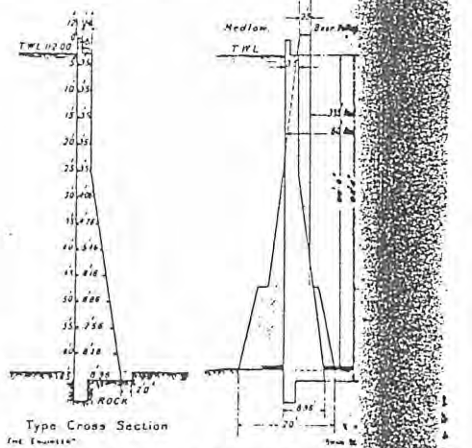


Fig. 4 SECTIONS OF MEDLOW AND BEAR VALLEY DAMS

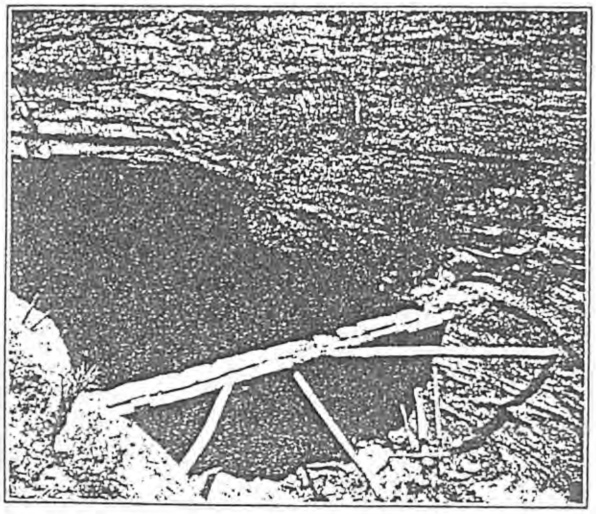


Fig. 2—TEMPORARY RESERVOIR FOR WORKING HYDRAULIC RAM

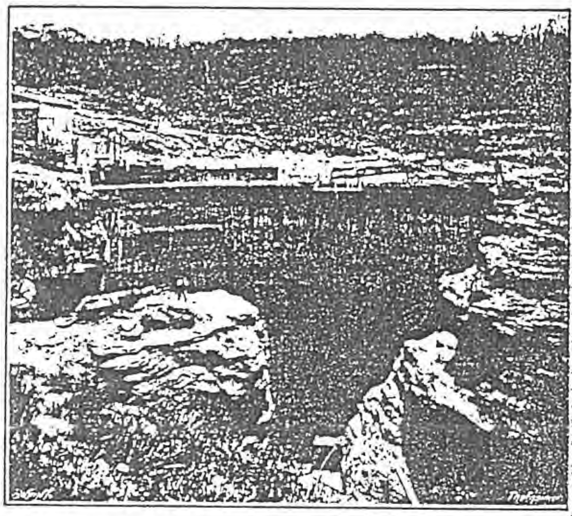


Fig. 3—MEDLOW DAM, SHOWING WATER SUPPLY PIPE

* See minutes of "Proceedings," Inst. C.E., vol. clxxviii., p. 2.

† This was before the building in 1907 of the Crawley Creek Dam in America.

[illegible] to the projections — was 1½in. inside diameter [illegible] long. The ram discharged into the upper [illegible] against a head of 130ft., exclusive of friction. [Under these] conditions the ram delivered 54 gallons [per hour]. Both tanks were filled before starting the [illegible], and with a continuous supply of 54 gallons [per hour] no shortage of water was experienced in [working] the forty-eight hours a week.

[The vertical] timbers supporting the profile boarding [illegible] Figs. 5 and 6—were of 6in. by 4in. hardwood, [illegible] of the concrete and connected thereto each [illegible] in. bolts with nuts at each end, built 10in. [into] the concrete. The bolts were oiled and no [difficulty] was experienced in unscrewing them from [the] [illegible], which were left in the concrete, the hole [being] then washed out and plugged with cement [illegible]. The lagging was of dressed T & G Oregon,

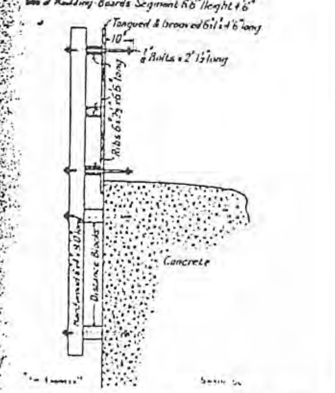


Fig. 5—ARRANGEMENT OF MOULDING BOARDS

[illegible] feet, nailed to 6in. by 2½in. dressed Oregon [illegible] ribs cut to radius, the segments being [illegible] deep and in 6ft. 6in. lengths. The face of [the] lagging was coated with soft soap immediately [before] the concrete was placed in position, the concrete being allowed to set for forty-eight hours before [the] profile boarding was removed. The concrete [was then] given a coat of cement wash.

[illegible] sandstone was met with in the foundations, but on either side considerably more [excavation] had to be taken out than was anticipated [from the] plans, as fissures and large bands of iron-[stone] running in all directions had to be contended [with]. Along the front line of trench at intervals of [illegible] holes reaching to the bottom of the foundation [illegible] in the rock, whilst chases were cut in [illegible] benches in each cliff. After the concrete

Fig. 6—PROFILE MOULDING BOARDING

[had] thoroughly set, iron pipes were temporarily [inserted] into the holes and chases, and cement [grout under] pressure was then forced down the pipes, [with a] view to filling any spaces between the rock [and the] concrete. There were several bad horizontal [seams in] the rock cliffs on the upstream side of the [dam, and] to prevent the wing walls being flanked, [these were] cleaned out with a water jet and [illegible] pipes being then cemented in and brought [to the] top of the dam. Cement grout was then [forced down] the pipes and the seams effectually [illegible].

[The] natural features of the site, in conjunction with the small radius of 60ft., rendered the [setting out] both easy and accurate, a fixed centre [and] measurements for fixing the radial points [illegible] and face line of wall being maintained for the greater portion of the height of the dam. A natural depression on one side of the gorge was fashioned into a spillway, discharging some little distance downstream of the dam, whilst the parapet wall of the dam itself, 3ft. above the overflow level of spillway, ensures the whole of the flood waters being passed into the creek without over-topping the dam—a matter of first consideration, with a thin wall without a water cushion at the base.

The catchment area is 1150 acres, with an average rainfall of 39in., the dam holding up a lake 0.62 miles long, with a water surface of 12 acres, containing 67 million gallons of very good water. The trees, stumps, scrub and undergrowth were cleared from the site of the reservoir, and the whole surface left bare to half a chain beyond the top water level, so that on the reservoir filling no trouble was met with from discoloration or decaying vegetable matter.

The work was completed in December, 1908, and although water was stored to within 19ft. of top-water level in the following February, it was not until the July that the spillway overflowed. The wall was then reported as weeping at two or three ladder rungs and at two pin holes at the 8ft. level, whilst a further weep was reported near top-water level, which, upon inquiry, was found to have resulted from the upsetting of a bucket of soft soap which was not washed off before the placing of the next batch of concrete. Whilst an efflorescent or deposit of lime brought out of the cement with the usual sweating was noticeable on the wall shortly after the first filling of the dam, yet the weeps were small and have now all taken up, leaving but a few small damp patches on the wall. The method of drawing off the water so as always to abstract from the clearest stratum at the top is shown in Fig. 7.

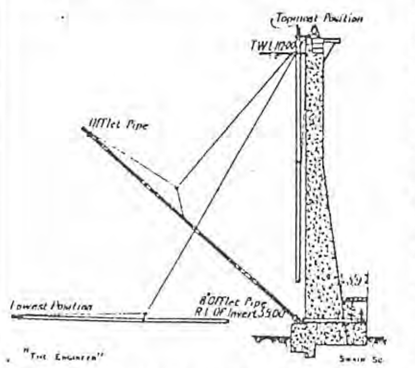


Fig. 7 METHOD OF DRAWING-OFF WATER

The dam was designed in the Public Works Department of New South Wales under the direction of the late Mr. L. A. B. Wade, M. Inst. C.E., then Chief Engineer for Irrigation and Drainage, the work being built by day labour under the supervision of Mr. Percy Allan, M. Inst. C.E., M. Am. Soc. C.E., then Principal Assistant Engineer for Water Conservation. The work cost £2762, exclusive of the expense involved in clearing the site of the reservoir, costs of supervision and engineering expenses.

SCREW GAUGES.

Neither the construction nor, once they have been constructed, the use of plain cylindrical limit gauges is a matter presenting any great degree of difficulty. In forming such gauges we have to work to three requirements. First, the gauges must be truly circular in cross-section. Secondly, they must be truly parallel in elevational section. Thirdly, they must approach their nominal diameter with an accuracy somewhat greater than that required in the work on which they are to be employed. In use the gauges are employed in pairs, one being to the small side and one to the large side, the difference in size being equal to the tolerance allowed in the work. The work must permit one of the gauges to pass into it or over it, but must not permit the other to do so.

There can be little dubiety about the operation. The gauges not only control the size of the work but indicate whether it has been turned with a taper. The feel of the "go" gauge in or on the work also indicates whether it is truly circular in section or slightly elliptical. Thus these gauges check the three elements of the work, viz., its size, its parallelism and its circularity.

The gauging of screws, on the other hand, is, if it is to be carried out thoroughly, a very complex operation, involving the expenditure of much time, an operator of considerable skill, and apparatus of a delicate and expensive nature. The trouble is that there are no fewer than seven different elements about a Whitworth screw thread which require gauging. These are the full diameter, the core diameter, the effective diameter, the pitch, the angle, the form at the crest and the form at the root. It is impossible to devise a practical system of limit gauges for these elements. In the case of an external thread it is, of course, easy to apply limit gauges to the full diameter, that is, the diameter over the crests of the threads. A similar remark applies to the core diameter of internal threads. The two most important elements, however, are the pitch and the effective diameter, and these two are the most difficult to control. The effective diameter, it may be explained, is the length of a line intersecting the axis of the screw at right angles and terminated at each end by the straight, sloping flanks of the thread. In a perfect screw the effective diameter is the mean of the full and the core diameters.

To illustrate how difficult it is to gauge a screw properly and completely it may be said that a perfect screw gauge would reject a screw perfect in any six of the above-named elements but imperfect in the seventh. Further, it would give us no indication as to which of the seven elements was at fault, for, with the exception of the two last elements, the radii at the crest and root, an error in one of the elements introduces a corresponding error in one or more of the others.

The matter is not made any easier by the adoption of "crossed limits" for many classes of screwed work. For example, the limits for a screw nominally ½in. in diameter may be 0.496in. and 0.500in., while for the tapped hole they may be 0.498in. and 0.502in. Selective assembly in this case is necessary. If the gauging is not carefully performed, or if the gauges themselves are not as accurately made as they should be, the difficulties of selective assembly will be considerably increased.

The whole subject is of much importance at the present time, for screwing and tapping to gauge play a considerable part in "munitions" work. Manufacturers, whether of munitions or of the screw gauges used in the work, will find very great assistance and enlightenment in a 28-page pamphlet which has been written by members of the staff of the National Physical Laboratory, and which has just been published, price 1s. 6d., by Mr. W. F. Parrott, The Causeway, Teddington. This pamphlet is entitled "Notes on Screw Gauges," and is to be highly commended on the score of its practical applicability. It deals primarily with the manufacture and the examination of the gauges themselves, but it is nevertheless of great value to all users of screw gauges as well as to those who have to make them. We may add that actual users of screw gauges will find additional help in Report No. 38 of the Engineering Standards Committee, wherein as an appendix there is described a complete system of gauging a screw, the method being that of Mr. W. Taylor.

Having explained the necessity for accuracy in a gauge, the Physical Laboratory pamphlet deals with the errors which may occur in screws, and methods whereby these errors may be discovered and measured and avoided in future work. Discussing first plug screw gauges, it explains that an ordinary micrometer is sufficient to check the full diameter. A word of caution, however, is uttered against the practice of using a hand chaser to finish a screw gauge thread. Hand chasers are rarely accurate enough for this work, even when fixed in the slide rest, and may result, if they are used, in the gauge being made seriously oval. A micrometer test will, of course, reveal whether the gauge is circular or not.

The effective diameter is more difficult to measure. A simple method of doing so by employing three needles inserted in the vees of the thread is explained. The diameter over the needles is measured by a micrometer,

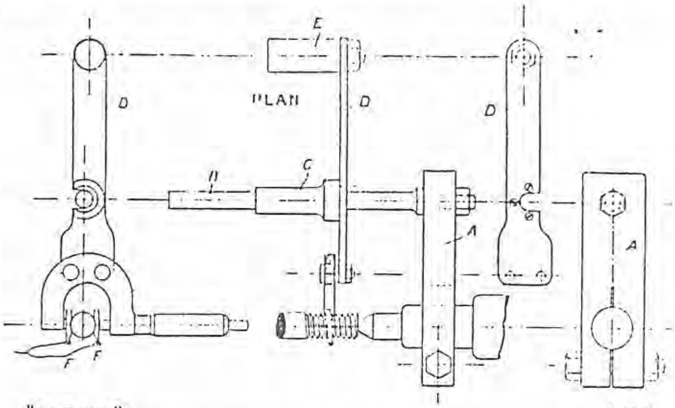


Fig. 1—METHOD OF CARRYING MICROMETER IN LATHE

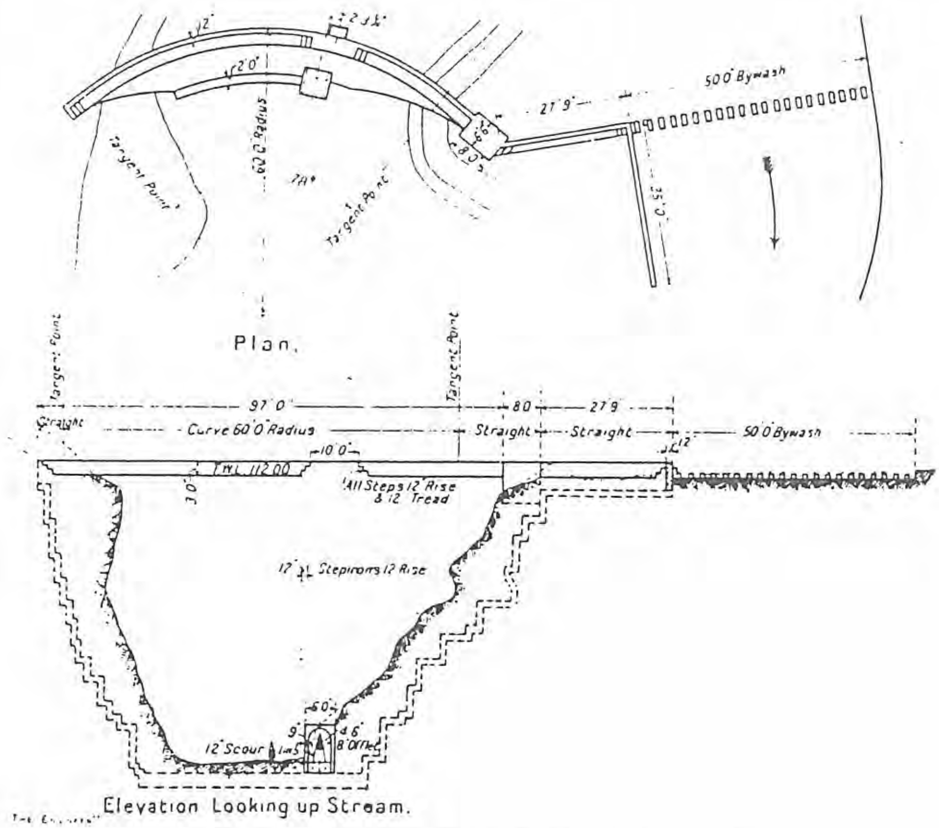


Fig. 1—THE MEDLOW DAM PLAN AND ELEVATION

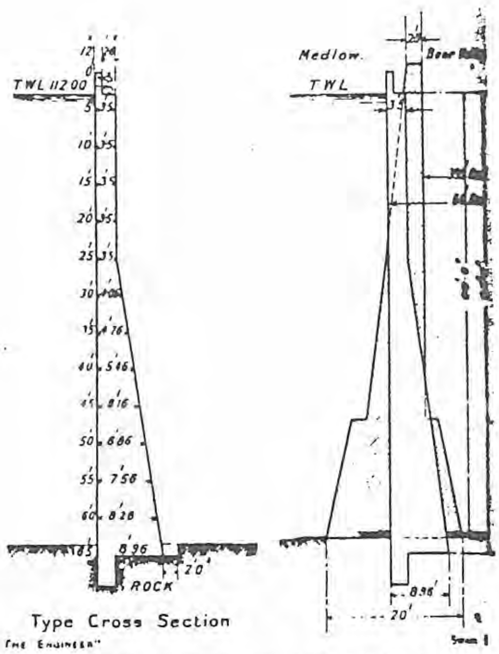
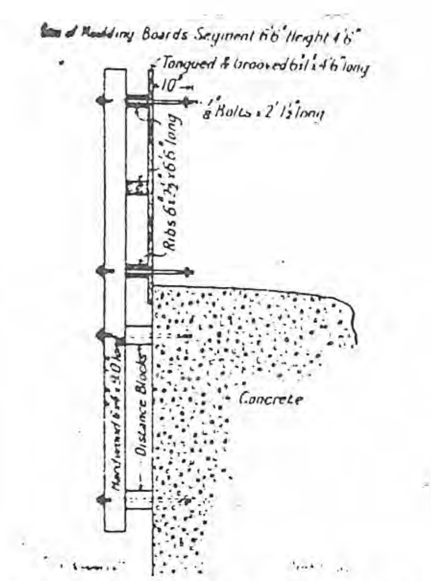


Fig. 4 SECTIONS OF MEDLOW AND BEAR VALLEY



ARRANGEMENT OF MOULDING BOARDS

Plans and Sections of Medlow Dam
The Engineer, March 24, 1914.

Sydney has not the reputation of being a model city. It is now believed that Government is about to take the control of the city in its teeth, and that the present holders of the reins will soon be supplanted. Every well wisher of Sydney, who sees and understands what magnificent latent possibilities there are before her must hope that she will for all time be the Queen City of the Southern Hemisphere; and that the new century will open finding old ways departed from, and a new and glorious era of progress, prosperity, morality and cleanliness installed in our midst. When that day arrives, we shall look back with curiosity and wonder at the continued blindness and negligence from which our city—so highly gifted by nature—had suffered so long.

CURVED CONCRETE WALLS FOR STORAGE RESERVOIRS.

By C. W. Darley, M. Inst. C.E.

[*Read before the Engineering Section of the Royal Society of N. S. Wales, December 19, 1900.*]

In carrying out water supplies for small country towns it is necessary to cut down the expenditure in every way possible, so as to keep the total cost within the means of the municipality to pay the interest and provide a sinking fund.

In a great many cases pumping schemes are available and would be much cheaper as regards first cost, but the working expenses are necessarily much higher than for a gravitation scheme, besides experience has proved that country municipal authorities will rarely employ competent skilled labour for looking after the engines, and in consequence many valuable pumping plants may now be seen in the State in a shockingly neglected condition, and complaints are made that the machinery is unsatisfactory and will not work, the sole reason being invariably due to dirt and wilful neglect.

Of late years, partly owing no doubt to the unfavourable reputation thus given to pumping plants, country municipalities have been urging the adoption of gravitation schemes. In only a few instances have these been available, providing an abundant supply within easy reach; while in others, good schemes have been provided by going some miles away, but several towns have had to be content with schemes having a very limited catchment area, and are thus dependent upon occasional thunderstorms and heavy showers to replenish the reservoir, and in some instances this somewhat doubtful supply has been preferred to a pumping scheme within easy reach

When carrying out gravitation schemes for some of the large towns such as Orange, Armidale, and Junee, concrete reservoir walls were erected with gravity sections. The section of wall adopted closely follows that recommended by Professor Rankin in his report on the Tansa Dam for the Bombay Water Works. This wall has a slightly battered inner or water face, the profile of the outer face being a logarithmic curve; this section has of late years been adopted for almost all large reservoir walls. Such a wall resists the pressure of water against it wholly by its own weight, and is consequently termed a gravity wall. Its principle as laid down by Professor Rankine is such that the centre of resistance of any horizontal plane ought not to deviate from the middle of the thickness by more than about one sixth of the thickness—inwards when the reservoir is empty, outwards when it is full—in order that there may be no appreciable tension at the outer edge of the given plane when the reservoir is empty, nor at the inner edge when it is full.

This is about the most economical section to which a dam can be constructed to resist the pressure by gravity alone; but in the case of many small towns the cost of such a dam would be prohibitive; the Department therefore had to resort to a more economical section of dam, and this could only be done by building it in a curved form and treating it as an arch, thus putting the concrete wholly in compression. Several large dams have been successfully constructed on this system in America, but it is only within the last few years that they have been introduced into this State.

A short description of some that have been erected may be interesting. Curved or arched dams can only be constructed when the valley is comparatively narrow and where sound rock can be obtained the whole way across and up each slope, to form good abutments. In some cases where the configuration of the country did not admit of a curve being fitted in from end to end, a short piece of gravity dam had to be constructed at one end from which to spring the arch. This was done at Tamworth and answered

the purpose well; and a similar arrangement is about to be carried out in a dam across the Cataract River for the Wollongong Water Supply.

Theoretically it would seem of little importance how the thickening of the dam was arranged; whether both sides should have a batter, thus keeping the centre of gravity of all sections in a vertical line in the centre of the dam, or whether the batter should be on the inner or water face, thus obtaining some help from the downward thrust of water on the batter which some engineers have contended to be of service, or to keep the inner or water face vertical and outer side battered. As a matter of fact we have examples of each form in the State. The Parkes Dam having a double batter, and the Tamworth Dam being battered on the inner face, but the standard practice now adopted, and one found in many respects most convenient in construction, is to keep the inner face vertical and the outer face battered. This arrangement suits the outlet works more conveniently, as the swivel offtake pipe can be brought close up to the face of the dam for cleaning without falling back too much.

Principles upon which the curved dams have been designed.—A curved dam with solid rock abutments being subject to the same stresses as a hollow empty vertical cylinder of the same radius, and surrounded on the outside by water of the same depth as that impounded by the dam, the formula for resistance of cylinders to a crushing pressure, viz.: $P=\frac{2sT}{D}$ or $\frac{sT}{R}$ has been used for calculating the thickness of the seven curved concrete dams or weirs constructed in connection with the Country Towns Water Works to date with radii varying from 100 feet to 300 feet.

The value of s (safe crushing strength of material per square foot) for a dam with granite or basalt abutments, the same stone being used for the concrete, has been taken at 20 tons, and for dams having sandstone abutments, as at Lithgow and Picton, at 10 tons to 12 tons per square foot according to local conditions.

T = Thickness at any point in feet.

R = Radius in feet.

D = Depth of water to be impounded which should be calculated from the maximum estimated highest overflow or flood level.

P = Water pressure in tons per square foot.

$$P = \frac{D \times 62{\cdot}5}{2240} = D \times {\cdot}027902$$

$$T = \frac{RP}{s}$$

$$\therefore T = RD \times {\cdot}0014 \text{ when } s = 20 \text{ tons}$$

$$T = RD \times {\cdot}0023 \text{ when } s = 12 \text{ tons}$$

The thickness of any curved dam at any depth may thus be graphically determined by a simple diagram the top thickness being increased to 3 ft. or 3 ft. 6 in. up to 5 ft., or more, where floating timber is expected to be carried over during floods. The area of the triangle forming the theoretically safe cross section $\times\ s$ = the total thrust on each abutment.

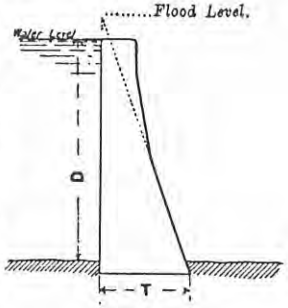


Fig. 1.

There would be no saving of material in constructing a concrete dam, having a limit of resistance of 20 tons per square foot to a greater radius than 500 feet or with a limit of resistance of 12 tons per square foot to a greater radius than 300 feet, because the required thickness would, in both cases, be about equal to that necessary for a dam of gravity section having a line of resistance within the middle third. A slight curve in all long dams is, however, advisable, to allow of more freedom of movement under changes of temperature, and to obviate as far as possible, transverse cracks due to the contraction of the concrete in setting.

The average crushing strength of a large number of specimens of concrete made with the usual proportions of dry materials, viz. 1 cement, $2\frac{3}{4}$ sand, $2\frac{1}{2}$ shivers, and 3 hard metal $1\frac{1}{3}$ in. gauge, six months old, has been ascertained by testing to vary from about 70 tons to 145 tons per square foot—80 tons may be taken as a safe average. Taking the concrete in place at one and a half times stronger than the unsupported test cubes gives an average crushing strength of 120 tons per square foot at least six months old, the factor of safety of the work at that age would therefore be 6 for a limit of resistance of 20 tons, and 8 for a resistance of 15 tons. Mr. Bruce in his paper on the strength of concrete (Proc. Inst. C.E., Vol. CXIII.) considers that the modulus of rupture, found experimentally, may be adopted as the working load in compression. The average modulus of rupture of 14 transverse tests of sandstone, and whinstone concrete made by him = 16 tons per square foot.

A limit of resistance so high as 20 tons per square foot should be used only for curved dams in cases where the foundation, abutments, and metal for concrete consist of sound, hard, igneous rock.

To provide against the green concrete being subjected to a greater head of water than it can safely bear during construction, the work is carried up in nearly level courses not more than 3 ft. in height, the depth of water being controlled by the scour and outlet valves. Should a flood occur during construction the walls may be submerged without much risk. This has happened in one or two cases, but no injury was done as the lower portion of dam is so much thicker in proportion. There would be more risk of course from flood waters crossing the top of a newly completed wall, but in all probability the extra thickness provided in the upper portion would make the work quite safe. In all calculations the weight of the wall has been disregarded although it must materially assist in its strength.

Details of construction of curved concrete dams.—It has been found advisable to construct all our concrete dams by labourers employed directly under the officers of the department without the intervention of a contractor. The reasons for this course are as follows :—Information as to the nature of the foundations can only be obtained from trial shafts, and this is often unreliable. The depths as shewn on the section for a contractor's guidance have to be exceeded in many instances to get down to strata

sufficiently solid to make a safe foundation, thus opening the way for contractors to set up claims which are difficult to dispute or adjust. Also, by employing a staff who are moved from one work to another and thus trained to the class of work, a more uniform standard of construction is obtained, and equally as cheap as if done by contract.

English, German and Colonial cements have been in use, but an effort is always made to have each dam carried out in one brand. Of late, the Rock brand cement, manufactured near Sydney by Messrs. Goodlet and Smith, has been almost exclusively used. It is packed in bags and is thus cheaply handled or carted. It is delivered as required from the store at Granville into railway trucks, and thus the expense of erecting large storage sheds on the site of the works is saved. The bags are found very useful for covering green concrete and other purposes.

All the sand used for making up the concrete is washed, the usual apparatus employed being the ordinary "Long Tom" of the gold-digger. A horizontal screen is placed at the head of the trough, this not only removes coarse stuff and vegetable matter, but also assists greatly in distributing the water through the mass, thus freeing the particles from dirt. The dust from the stone-crusher, if granite is being broken, mixed with the washed sand is found to add to the strength of the concrete.

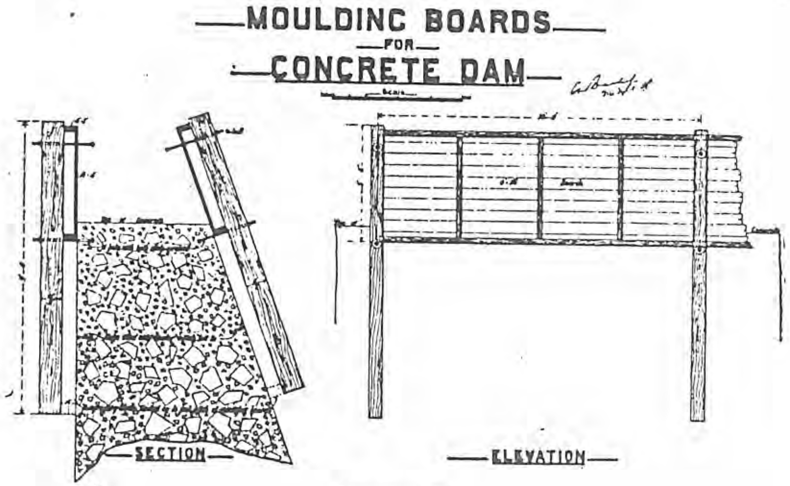
Stone is broken up into ballast and shivers by the ordinary types of stone-crushers and passed through a revolving screen to separate the various sizes. The "Little Giant" type of crusher has been generally used, as the pin-plates provided with this machine best stand the wear of breaking to the small gauge of $1\frac{1}{2}$ inch. The pins are of $\frac{3}{4}$ inch tool steel set in a cast-iron backing. Manganese steel plates have been tried, but sufficient experience has not yet been gained to enable me to express an opinion as to their wearing qualities.

As a rule, the rock foundations when laid bare are sufficiently rough to give a grip to the concrete, and it is not necessary to cut

skewbacks to take the thrust of the arch. This also applies to the joint under the base, very little artificial roughening being required to make it water-tight.

In preparing the foundation care is taken to remove all soft, loose or shaken rock, and to roughen or step all smooth and inclined surfaces. The rock is then well washed with a jet of water under a pressure of about 20 lbs. per square inch, and all joints, fissures, etc., raked out and carefully grouted, or stopped with cement mortar. A half inch layer of mortar is then spread over the rock surface and worked into all corners and recesses, and upon this while fresh, the concrete is deposited.

The wall is brought up in 3 feet courses, each course consisting of three 12 in. layers carried along, one slightly ahead of the other. The course is held between mould-boards 10 ft. long by 3 ft. 6 in. high, framed of 4 in. by 2 in. hardwood, sheathed with 4 in. by $1\frac{1}{4}$ in. tongued and grooved pine.—(See diagram). Sufficient of these should be made to carry a course the full length of the dam. The mould-boards overlap the preceding lower course 6 in., and are held in position by 8 in. by 4 in. hardwood profiles attached



Drawing 2.

to the inner and outer faces of the wall below. The attachment is by $\frac{3}{4}$ in. bolts screwed at both ends, a bolt and nut is built 6 in. into the concrete at intervals of 10 feet horizontal and 3 ft. vertical. When a course is completed, the mould-boards and profiles are lifted 3 ft.; unscrewing the bolts leaves the nuts in the wall, and the bolt-holes are then filled with mortar. The mould-boards are curved to the mean radius of the face of the wall. On the down-stream or concave face the radius increases as the work is carried up, and the mould-boards gradually separate. Filling pieces have to be inserted between the mould-boards; on the upstream or vertical face this does not occur.

The proportions of the ingredients of the concrete used in the body of the wall are—1 cask of cement, $4\frac{1}{3}$ cubic feet; 12 cubic feet of sand; 10 cubic feet of shivers, $\frac{1}{2}$ inch gauge; 13 cubic feet of metal, $1\frac{1}{2}$ inch gauge. A six inch facing is used on the water side of the wall composed of 1 cask of cement, $4\frac{1}{3}$ cubic feet; 10 cubic feet of sand; 10 cubic feet of shivers, $\frac{1}{2}$ inch gauge.

Plumstones to the maximum size that can be handled by two men are built into the body concrete as closely as will allow of proper ramming and packing round them. They can be most efficiently bedded on their thinnest edges, and should have their greatest length radial to the curve of the wall. With careful packing, and selecting stones of square dimensions, it is possible to get 45% of stone into the work, but in dams of small radius and therefore thin walls 33% of plumstones should only be calculated upon. These small stones have been found to be the most economical size to use; as the dams built for the supply of water to country towns are rarely large enough to bear the expense of providing plant for lifting larger weights the economy of the use of plumstones is obvious.

The practice has been to use the richer concrete on the water-face to make a water-tight wall. Experience has shewn the impermeability of the structure depends almost wholly on the skin worked up on both faces of the concrete. This skin consists of a thin layer of neat cement, which is obtained by working a spade or

suitable tool between the concrete and the mould-board. It is best obtained by placing the concrete in position in a fairly wet condition. But wet concrete contracts by the gradual escape of excess moisture and vertical cracks would appear in the wall, and therefore to guard against this it becomes necessary to use the concrete as dry as possible and ram thoroughly. To obtain the impervious skin the concrete face should be floated with neat cement immediately the mould-boards are removed and while it is in a green and moist condition.

The whole of the concrete is run in on a tramway of a gauge narrow enough for the skips to pass between the mould-boards on the thinnest part of the wall. If the site is suitable, the stone-crusher, mixing boards, etc., are placed so that the material gravitates through all the processes to the work. Where the pipes pass through the dam they are carefully cleaned, washed over with cement grout and bedded in, and surrounded by one to one cement mortar.

Outlet Works.—The outlet works generally consist of a large cast-iron scour pipe, usually 24 inch diameter, controlled on the outside by an ordinary double faced stop valve operated from the top of the dam. At the inner end of the pipe a bell mouth is formed in the concrete to facilitate the insertion of a wooden ball should the necessity arise to remove or repair the stop valve. A cast iron offtake pipe about twice the capacity of the proposed main is built into the wall at a somewhat higher level than the scour pipe and fitted on the outside with a stop valve, and on the inside with a trunnion joint and moveable wrought iron galvanised pipe with a galvanised wire netting screen at the end. By means of an ordinary crab winch fixed to a platform on the top of the dam, the offtake pipe can be lowered or raised as required, so as to draw off near the surface, it can also be hauled up to the vertical position and the screen cleaned when necessary. In small reservoirs where there is little wave action, the moveable pipe is buoyed by a float. The crest of the dam forms the waste weir, which is made as long as possible where the catchment is large.

As far as possible it is desirable to avoid constructing concrete dams, certainly the upper or thin portions during very hot weather. It has been found by experience that walls so constructed are far more liable to crack during succeeding cold weather, especially in the case of reservoirs that have not been filled for some time after completion, thus allowing them to thoroughly dry out and contract. However, although the cracks, which in some cases may extend almost the whole way down the wall, are very unsightly and alarming to the uninitiated, they need really cause no anxiety to the engineer, for soon after the dam fills with water, thus moistening and expanding the concrete, and partly no doubt pressing home the arch, the cracks close up and fine particles of matter in the water render them water-tight.

In the case of the Tamworth dam, the top portion of which was built during warm weather and remained dry till after the very cold winter had set in, some apparently large cracks appeared, but they all closed soon after the reservoir was filled, so much so that it is now quite impossible to detect where they were, likewise in the Mudgee dam constructed under similar circumstances as regards heat, etc., which also remained unfilled for over a year, several large cracks appeared, some open as much as ⅛ in. on top, but they all closed up soon after the first filling. In this respect curved dams have a decided advantage over straight gravity dams, for when the latter form of wall cracks, which all long walls of concrete are liable to do when subjected to change of temperature and stand dry for any length of time, they do not so readily close up again.

Cost of curved concrete dams.—The cost of material of course varies at each site, according to length of rail carriage distance, for carting from railway, distance from suitable stone or sand, and cost of labour vary with adaptability of site for economical working. The actual cost is best illustrated by taking a fair average case in practice and giving the cost in detail. In the case referred to, the distance of rail carriage was 253 miles, and road carriage six miles. Sand was obtained from a dry creek three miles

from the works; and stone from a diorite quarry about 200 yards from the dam, but in this case the quarry being below the level of the dam all the material had to be lifted.

Cost for one cubic yard of each ingredient used in concrete:—

	s.	d.
Sand—Getting and washing	3	7
Carting	1	11
Cost of sand per cubic yard...	5	6
Rubble stone—Quarrying	3	8
Explosives, etc.	0	7
Cartage	0	7
Cost of rubble stone per cubic yard ...	4	10
1½ inch metal and ½ inch shivers—Quarrying ...	4	0
Explosives	0	7
Crushing and cartage	4	0
Cost per cubic yard	8	7
Cement—Cost price of cement per cask ...	9	9
Freight, 253 miles rail	5	9
Cartage, 6 miles	0	8
Cement per cask	16	2

Cost of one cubic yard of aggregate in wall on a total of 2,763 cubic yards:—

	Quantity.	Per unit. s.	Per unit. d.	£	s.	d.
Cement, cask	.581	16	2		9	4·71
Grout, cask	·0119	16	2			2·31
Sand, cubic yard	·243	5	6		1	4·04
Metal and shivers, cubic yard ...	·435	8	7		3	8·8
Rubble stone cubic yard ...	·482	4	10		2	3·93
Timber in casing						3·62
Labour fixing timber						6·8
Labour, mixing and placing, including tools gear, etc.					4	0·5
Carting material and mixing boards						6
Erection of plant, building and temporary dam for water supply						10·8
Cost of plant charged to works						5·77
Freight and cartage on plant					1	0·7
Taking down plant and clearing up						2·22
Total cost per cubic yard of dam				1	5	0·20

In this instance about 45% of plum stone was worked in with the concrete.

Attached is a statement of eight curved dams designed, seven of which are complete, the eighth, namely that for the Wollongong Water Supply, is just about to be constructed. The leading dimension and capacity are given in each case as well as the nature, specific gravity, and weight per cubic foot of the stone used in the concrete.

The following table gives particulars of the curved dams constructed to date, also the weight of stone used in the concrete, and capacity of reservoir.

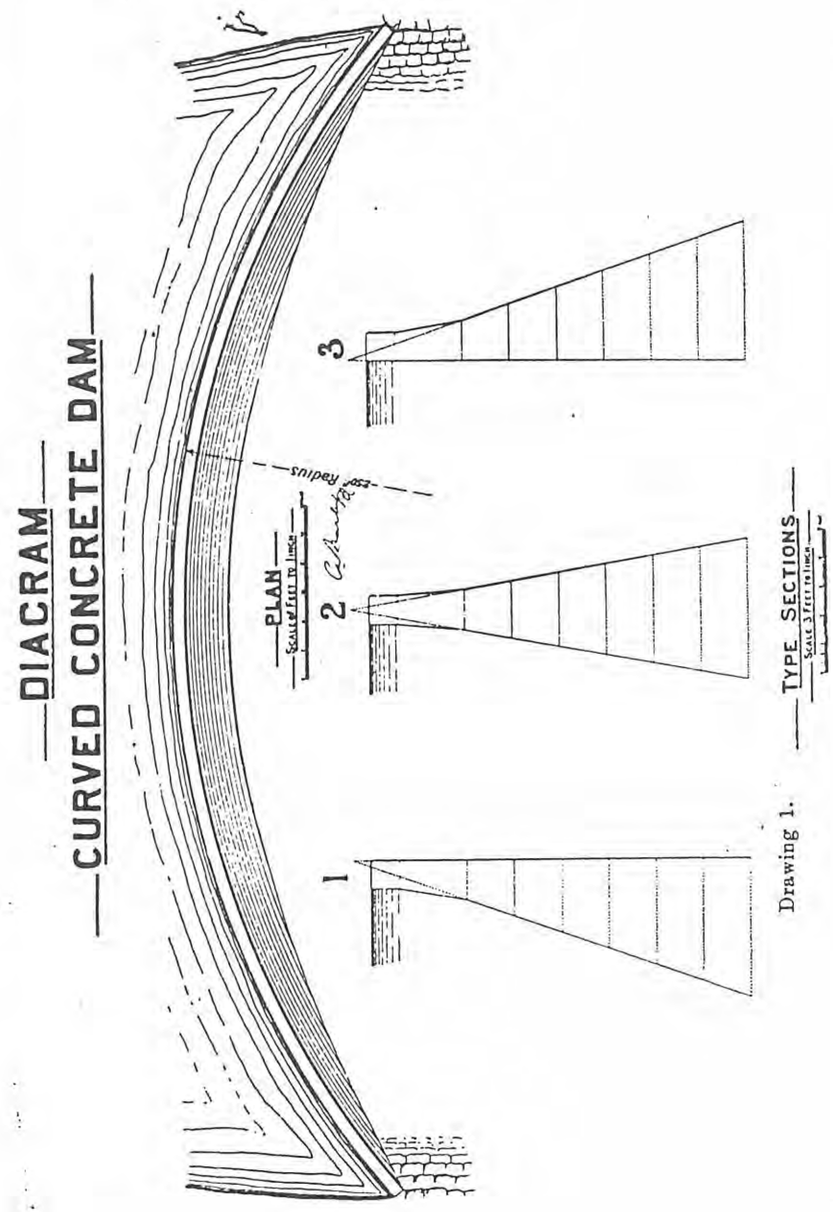
Name.	Greatest Height. Ft. In.	Length in feet.	Radius in feet.	Nature of rock.	Specific gravity.	Weight in pounds per cubic foot.	Calculated limit of pressure in tons.	Capacity in million gallons.
Lithgow ...	35 0	178	100	sandstone ...	2·34	146	10	15
Parkes ...	33 0	540	300	granite ...	2·75	171½	24	115
Cootamundra	45 6	500	250	diorite ...	{ 2·69 2·66	168 166 }	20	136·5
Tamworth ...	61 5	443	250	granite ...	2·71	169	20	50
Picton ..	*28 0	112	120	sandstone ...	2·36	147	12	14
Wellington...	48 0	350	150	conglomerate	2·67	166½	20	30
Mudgee ...	50 0	498	253	altered slate	2·69	168	20	42
Wollongong	42 0	528	200	basalt	...	...	20	168

* Designed to be raised a further 15 ft. hereafter if necessary, making 43 ft. in all.

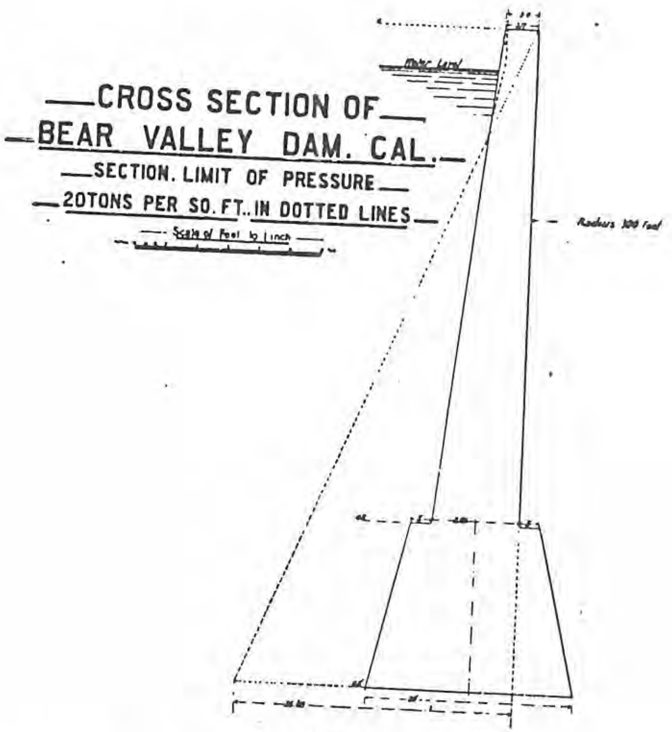
Drawing No. 1 shews the plan of a curved dam and three sections of dams constructed, section No. 3 being the type now mostly adopted and recommended.

Drawing No. 2 illustrates the method of timbering as described in the paper.

Drawing No. 3 shews a section of the Bear Valley Dam erected in California, U.S.A. This is a somewhat remarkable section, having an apparently very heavy foundation and an almost parallel wall on top—in this case the lower portion of the dam must be subjected to a compression of about 43 tons per square foot. I have drawn on in dotted lines the section of dam adopted in the State for sake of comparison.



Drawing 1.



Drawing 3.

The Tamworth and Picton concrete reservoir walls were carried out by Mr. S. H. Weedon, as Resident Engineer; the Parkes and Mudgee concrete walls by Mr. H. Fleming, Resident Engineer; and the Cootamunda and Wellington concrete walls by Mr. J. Symonds, Resident Engineer. In each case these officers had charge of the pipe laying and all other works in connection with the water supply as well. Mr. L. A. B. Wade, M. Inst. C.E., Supervising Engineer, had the general direction and supervision of all the works above referred to.

EXPERIMENTAL INVESTIGATION ON THE STRENGTH OF BRICKWORK WHEN SUBJECTED TO COMPRESSIVE AND TRANSVERSE STRESSES.

By Prof. W. H. Warren, M. Inst. C.E., M. Am. Soc. C.E., and S. H. Barraclough, B.E., M.M.E., Assoc. M. Inst. C.E.

[*Read before the Engineering Section of the Royal Society of N. S. Wales, December 19, 1900.*]

1. The following investigation comprises tests of brick columns and of brick beams built both in cement and in lime mortars, together with tests of the materials used in building the columns and beams. A special effort was made to keep the conditions as uniform as possible. The bricks used were all of one quality; the sand in the mortar was Neapean River sand sifted through 400 and caught on 900 meshes per square inch. The Portland cement was Hemmoor brand, obtained from one shipment; the lime was ordinary stone lime of uniform quality. The proportions of sand, of cement or lime, and of water used in making the mortar were accurately measured and the materials were mixed in a uniform manner. The same bricklayer was employed to build all the columns and beams; and the joints were maintained the same thickness throughout.

2. *Compression Tests.*—The columns were about 56 inches long and 9 inches by 9 inches or 14 inches by 9 inches in section, (Figs. 1 and 2). They were built on planed cast iron face plates specially constructed for the purpose, and were finished accurately on their upper ends to plane surfaces. In lifting them into the machine the columns were held between the upper and lower face plates under a slight initial compression of about half a ton by means of bolts passing through lugs on the face plates; the bottom plate was allowed to rest upon a ball bearing, and the top plate was removed before testing so that the top of the column was brought

The Medlow Dam, New South Wales.

The Construction Shows the Thinnest Profile in the World.

By Percy Allan, M.Inst.C.E., M.Am.Soc.C.E.*

The Medlow dam, on account of its slender profile is one of the most remarkable in the world, and is but a sheet of concrete in a sandstone gorge on Adams Creek, in the Blue Mountains of New South Wales. The wall, with a vertical upstream face, is built on a curve of 60 ft. radius, and is 65 ft. high from the foundation to the top of the parapet. The wall has a base width of only 8.96 ft., tapering on the downstream face to 3 ft. 6 in. at a height of 29 ft., thence 3 ft. 6 in. to top water level, finishing with a parapet wall 1 ft. thick for the remaining 3 ft. of height.

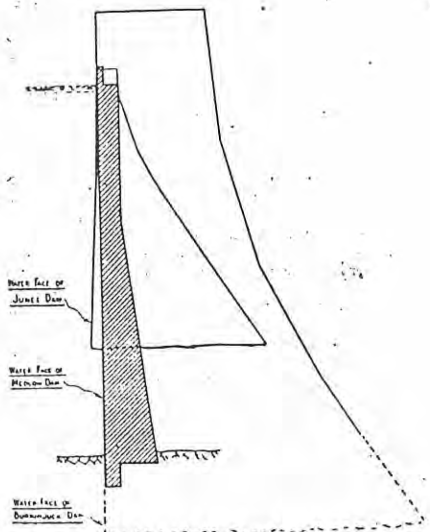


Fig. 1.—Comparative profiles of Medlow, Junee and Burrinjuck dams.

The profile of the gravity dam at Junee, illustrated in Fig. 1, shows at a glance the great saving in material effected by adopting a curved dam in a site so exceptionally suitable as at Medlow.

Whilst the water pressure at the overflow level is, of course, height for height the same in the 3 dams shown in Fig. 1, yet practical considerations really determine the top thickness and required freeboard. Thus at Medlow the provision of a 2 ft. 6 in. pathway for traffic across the dam decided the 3 ft. 6 in. thickness, whilst calculation showed that with a flood occurring on top of a full reservoir the water would be running 2 ft. deep through

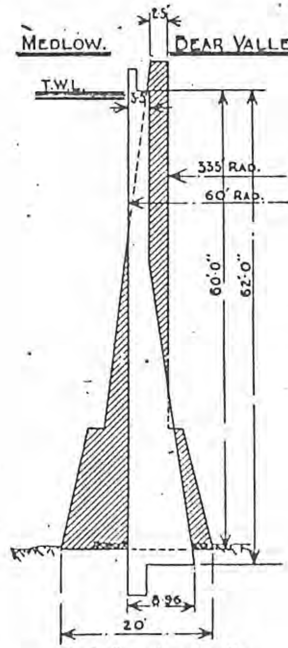


Fig. 2.—Comparison of profiles.

the spillway, and with practically no fetch to cause waves, a freeboard of 1 ft. was considered sufficient, thus giving a parapet wall 3 ft. above the overflow level.

In the case of Burrinjuck, however, a flood of the big Murrumbidgee River on top of a full reservoir with big waves from a long fetch has to be taken care of, which, with the provision for traffic across the dam, no doubt accounts for the freeboard and the thickness of the wall adopted.

* Public Works Department, Sydney.

Although the old Bear Valley dam, built in California in 1884, and superseded in 1911 by a multiple arch dam, has in the past been referred to as having the thinnest profile in the world, yet a dam built on Crowley Creek, in America, in the same year as Medlow Dam has a thinner profile, whilst Fig. 2 shows the profile of the Medlow dam to also be thinner. The Medlow wall, however, is —due to the narrow gorge—built on a very much smaller radius, viz., 60 ft. as against 335 ft., the maximum pressure on the concrete being only 12 tons per square ft., as against 53 tons per square

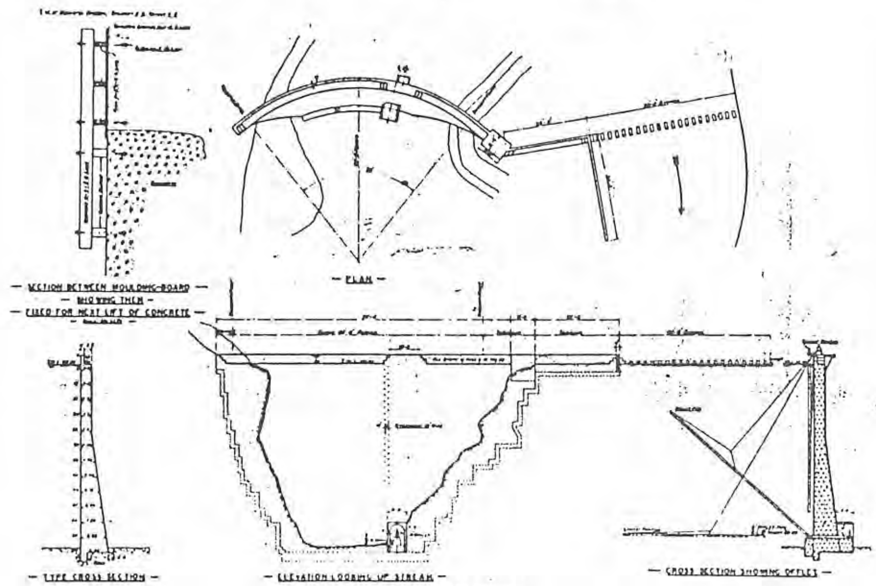


Fig. 3. Section and elevation.

ft. on the granite voussoirs in the old Bear Valley dam.

In determining the profile of the Medlow dam, the wall was treated as a section of a rigid cylinder, subject to external water pressure, any assistance due to the weight of the wall being disregarded.

The formula used was:— $T = \frac{RP}{S}$

where T denoted the thickness of wall at any level in feet,

where R denoted the radius in feet,

where P denoted the water pressure in tons per sq. ft., and

where S denoted the stress in tons per sq. ft.

The limiting pressure adopted for the concrete was 12 tons per sq. ft., whilst the highest water surface was taken as within 1 ft. of the top of the parapet wall, or 2 ft. above the overflow of spillway.

$$T = \frac{62.5 \times 62}{2240} = 1.73 \text{ tons}$$

$$\therefore T = \frac{60 \text{ ft.} \times 1.73 \text{ tons}}{12} = 8.65 \text{ feet}$$

The dam is built of concrete without any reinforcement or "plums." The concrete was composed of 13 cubic ft. of ironstone 2 in. gauge and 8 2/3 cubic ft. of ¾ in. screenings, to 13 cubic ft. of sand, to 375 lbs. of cement.

With a view to determining the crushing strength of the concrete as under actual conditions in the work, samples were taken from time to time off the banker board, just as the concrete was being placed in the work, and were then made into 6 in. cube blocks. The seven blocks tested showed at two months a crushing strength of 93

tons per sq. ft., and at three months from 93 tons up to 116 tons per sq. ft.—the limit of the machine. One block, however, at 35 days also beat the machine at 116 tons per sq. ft.

Good close sandstone was met with in the foundation trenches; but on either side considerably more excavation had to be taken out than was anticipated in the office plans, as fissures and large bands of iron stone running in all directions had to be contended with.

Along the front line of trench, at intervals of 6 ft., holes, reaching to the bottom of foundation, were left in the concrete, whilst chases were cut in the different benches in each cliff. After the concrete had thoroughly set, iron pipes were temporarily cemented in the holes and chases; cement grout under pressure was then forced down the pipes with a view to filling any spaces between the rock face and concrete.

The whole of the concrete was mixed by hand, on a platform located at the top of the southern cliff, and delivered thence into a hopper provided with a long timber chute reaching to the bottom of the foundation, or such position on the wall as required.

Fig. 3 shows various sections, etc., of the dam; Fig. 4 illustrates the upstream face of the dam and profile boards, and Fig. 5 shows the finished dam.

To provide a supply of water for concrete, two small tanks with earthen bag wall dams were excavated at a level to command the mixing platform, the water being raised from the creek bed by means of a No. 7 Danks' hydraulic ram. To obtain the necessary head of 12 ft. for working the ram, a timber dam faced with a clay bank was built some little distance upstream of the site; thence along the bed of the creek was laid the drive pipe of artesian bore casing, some 480 ft. long by 4 in. outside diameter. The delivery pipe was 1½ in. inside diameter and 335 ft. long. The ram discharged into the upper tank against a head of 130 ft. exclusive of friction. Under these conditions, the ram discharged 54 gallons per hour. Both tanks were filled before starting the concreting, and with a continuous supply of 54 gallons per hour, no shortage of water was experienced in working the 48 hours a week. A batch of concrete was usually found to require 35 gallons of water.

The vertical timbers supporting the profile boarding were of 6 in. x 4 in. hardwood, blocked off the concrete and connected thereto each with two ⅝ in. bolts, with nuts at each end, built 10 in. into the concrete. The bolts were oiled and no difficulty was experienced in unscrewing them from the nuts, which were left in the concrete, the hole being then washed out and plugged with cement mortar.

The lagging was of dressed T. and G. oregon, 1 in. thick, nailed to 6 in. x 2½ in. dressed oregon horizontal ribs cut to radius, the segments being 4 ft. 6 in. deep and in 6 ft. 6 in. lengths. The face of the lagging was coated with soft soap immediately before the concrete was placed in position, the concrete being allowed to set for 48 hours before the profile boarding was removed; the concrete face was then given a coat of cement wash.

A natural depression on one side of the gorge was fashioned into a spillway, discharging some

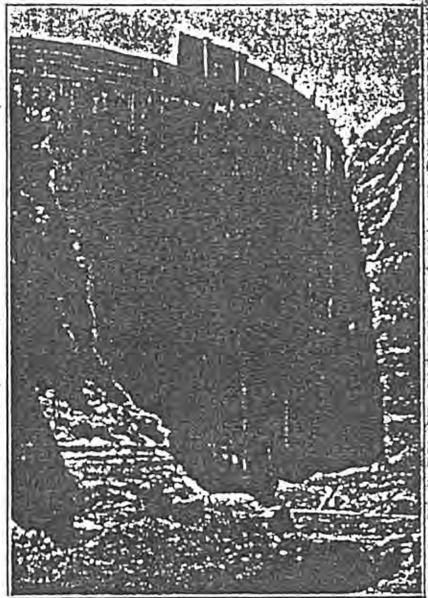


Fig. 4.—Showing upstream and face of dam and profile boards.

little distance downstream of the dam, whilst the parapet wall of the dam itself, 3 ft. above the overflow level of spillway, ensures the whole of the flood waters being passed into the creek without over-topping the dam—a matter of first consideration, with a thin wall without a water cushion at base.

The catchment area is 1150 acres, with an average rainfall of 39 in., the dam holding up a lake 0.62 miles long with a water surface of 12 acres, containing 67 million gallons of very good water. The trees, stumps, scrub, and undergrowth were cleared from the site of the reservoir and the whole surface left bare to half a chain beyond the top water level, so that on the reservoir filling no trouble was met with from discoloration or decaying vegetable matter.

The work was completed in December, 1907, and although water was stored to within 19 ft. of top water level in the following February, it was not until July, 1908, that the spillway overflowed. The wall was then reported as weeping at several of the ladder rungs and at two pin holes at the 8ft. level, whilst a further weep was reported near the top water level which, upon enquiry, was found to have resulted from the upsetting of a bucket of soft soap, which was not washed off before the placing of the next batch of concrete. Whilst an efflorescent or deposit of lime brought out of the cement with the usual sweating is noticeable on the wall, yet the weeps have now taken up, the wall being dry with the exception of some damp patches at one or two places.

The dam was designed in the public works department of New South Wales, under the direction of the late Mr. L. A. B. Wade, M.Inst.C.E., then chief engineer for irrigation and drainage, the work being built by day labour under the supervision of Mr. Percy Allan, M.Inst.C.E., M.Am.Soc. C.E., then principal assistant engineer for water conservation. The work cost £2762, exclusive of expense involved in clearing the site of the reservoir, costs of preliminary investigation, survey, supervision and engineering expenses.

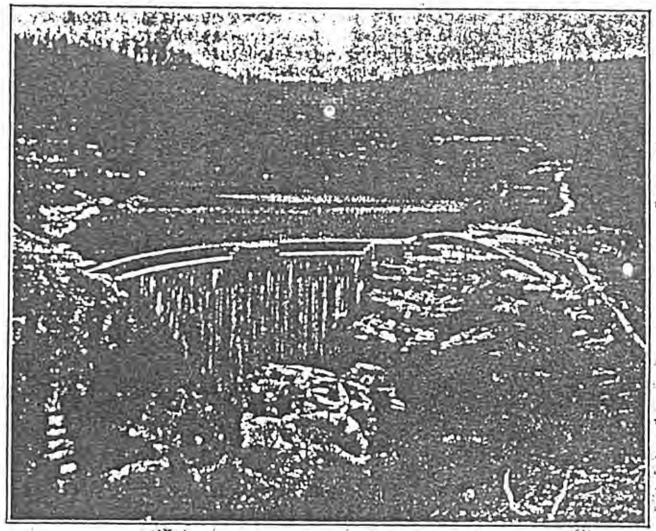
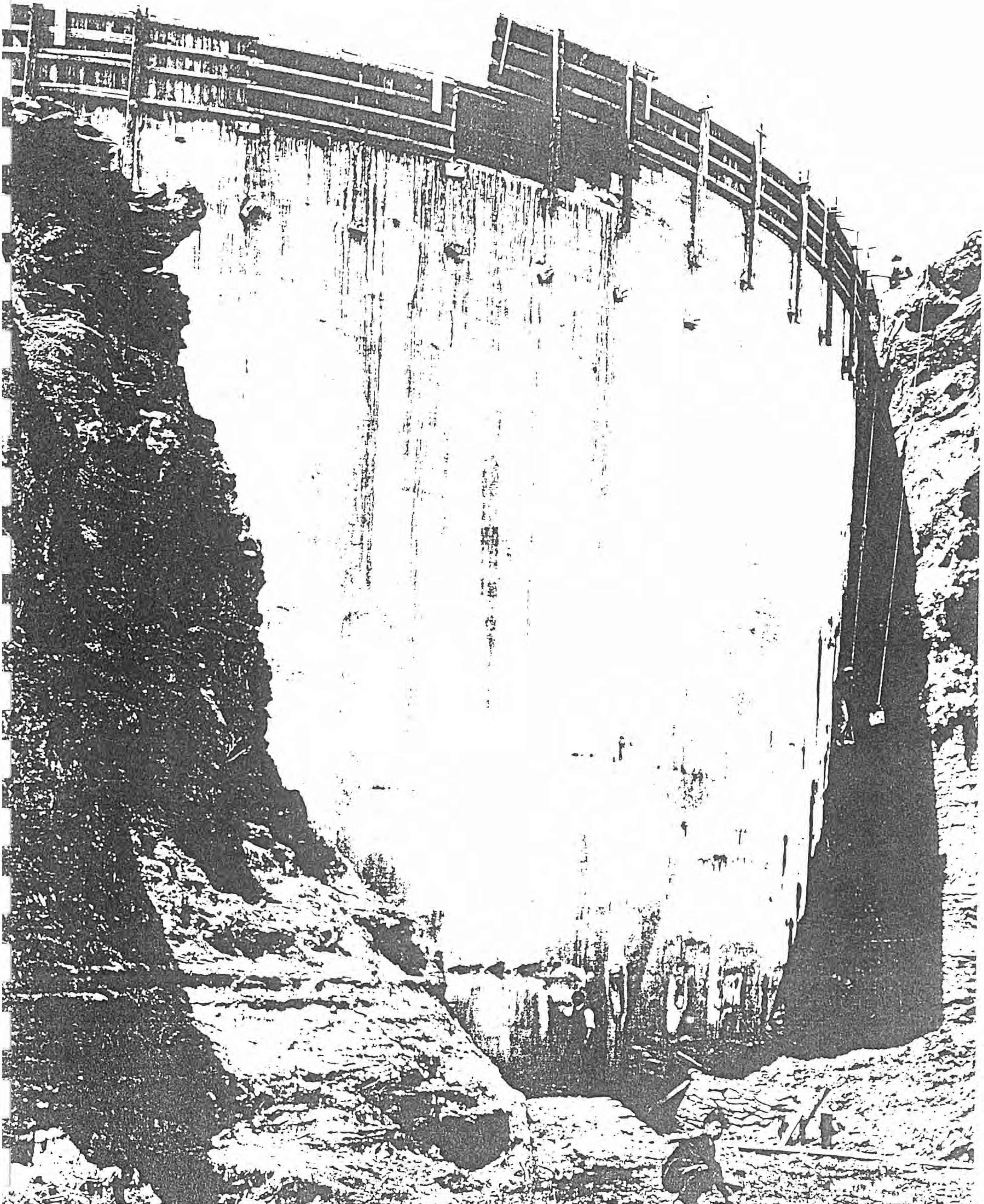
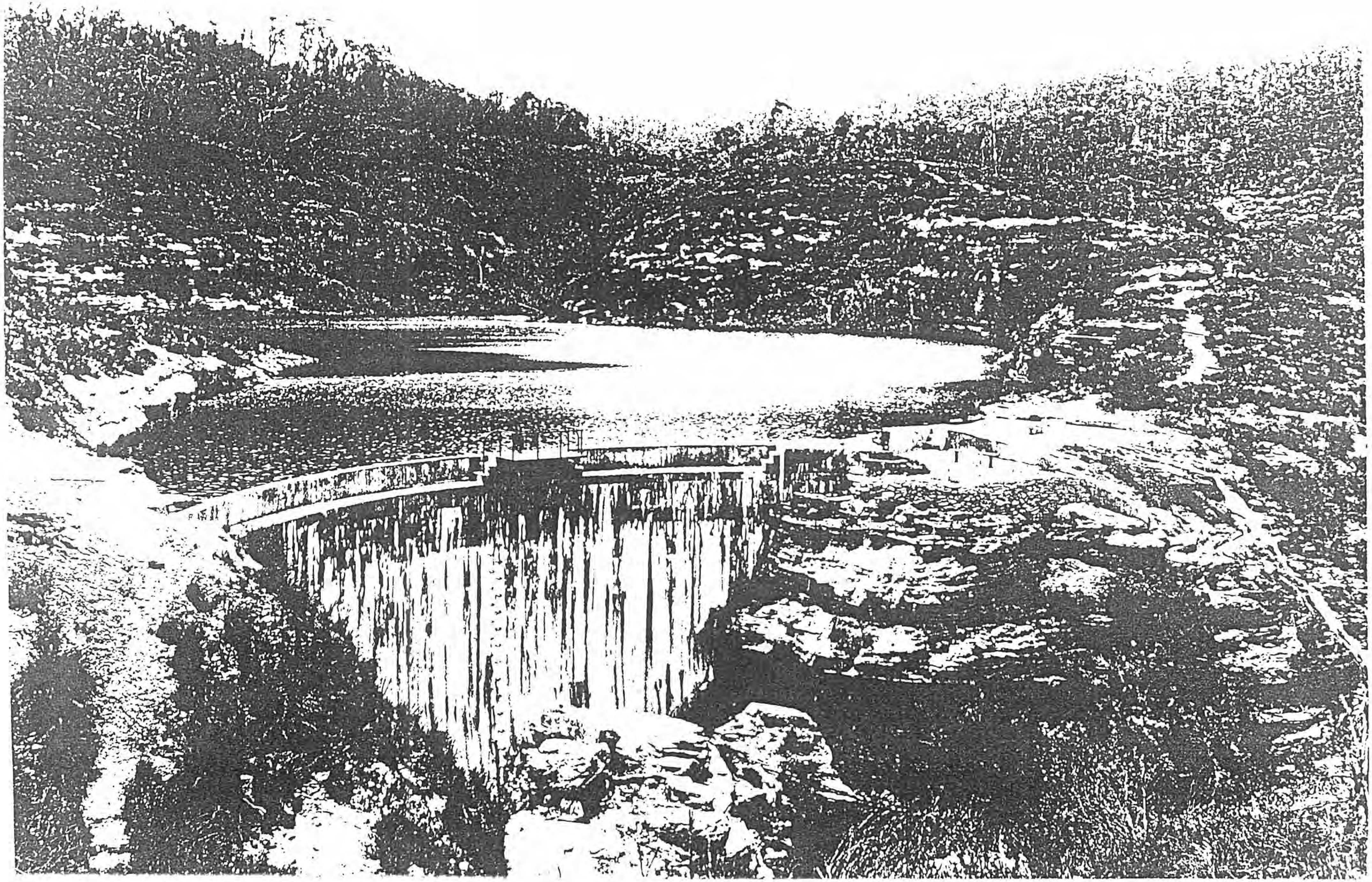


Fig. 5.—The Finished Dam.

The proposal of Mr. E. M. de Burgh, engineer-in-chief for water supply, N.S.W., to erect a dam on the Cordeaux river for the storage of water necessary for the maintenance of Sydney's supply, was laid before the parliamentary standing committee on public works last month. The scheme is to erect the dam immediately below the junction of the Cordeaux creek, to impound a further storage of 15,858,490,000 gallons of water. The dam is to be constructed of cyclopean concrete, 160 feet high from bed of the river, and 1525 feet long at crest, involving the use of 177,396 cubic yards of concrete. The storage will cover an area of 1603 acres; the full supply level will be 985.93 ft. standard datum. The cost is estimated at £490,000.

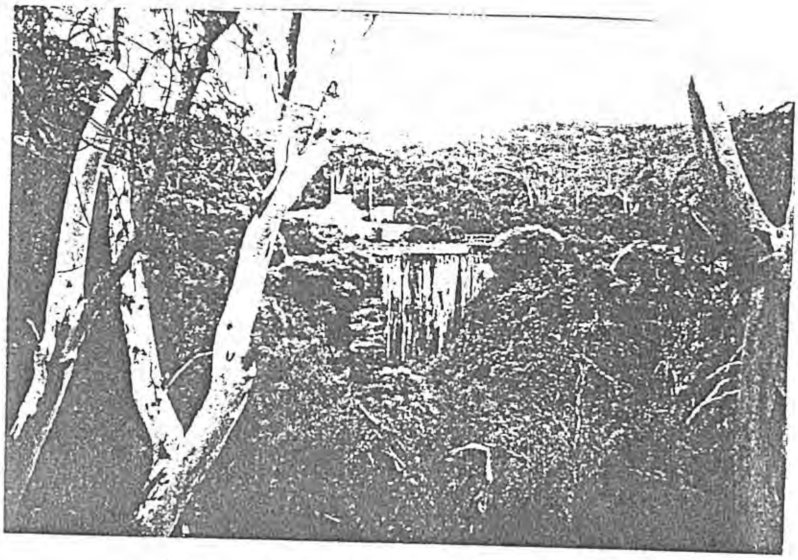


MEDLOW

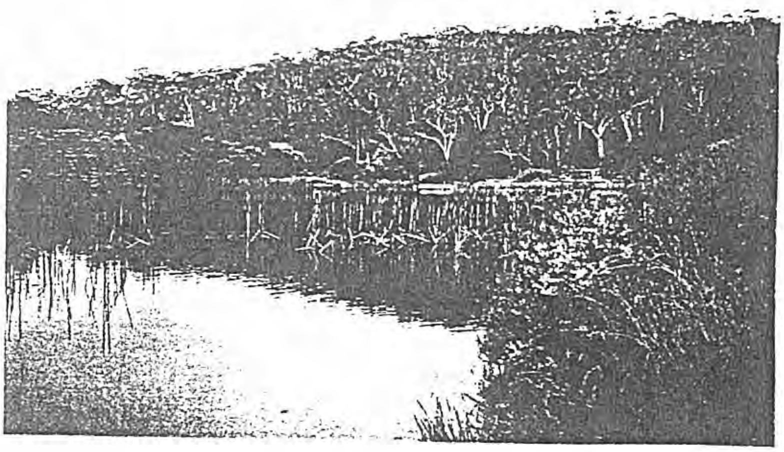


Medlow

PHOTOGRAPHS AND CONTEMPORARY NEWSPAPER EXCERPTS



Note large concrete Slab, April 1993.



Looking back Over the Dam, April 1993

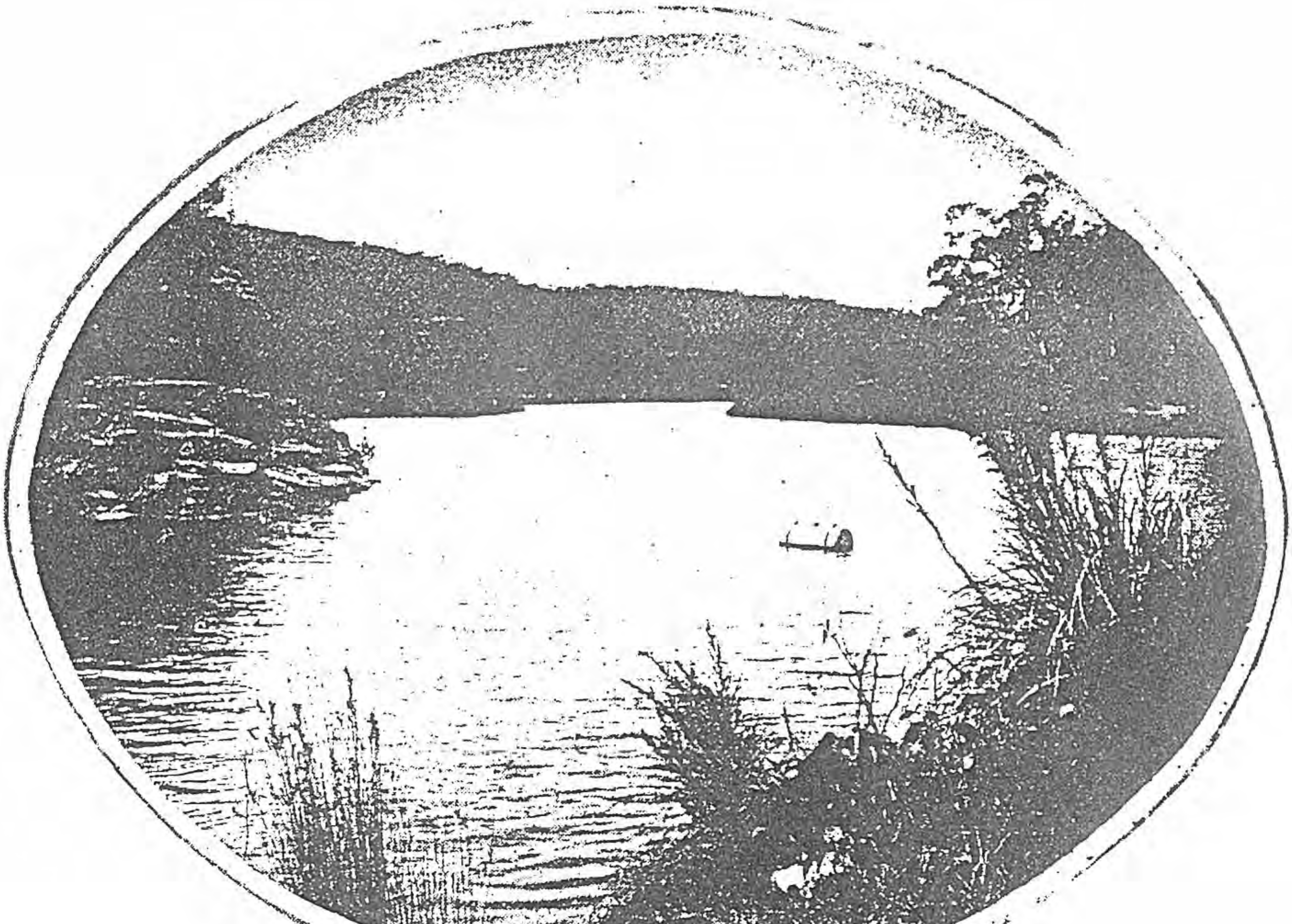


Illustration from Tourist Brochure *Views of the Far Famed Mountains* with Photographs by Harry Phillips

Water Board plans action for quality drinking water

The Water Board has identified a number of key strategies to improve the quality of drinking water to Blue Mountains residents, according to a Water Board document released last week.

Addressing complaints such as stained washing, the need to boil water after storms and the increasing difficulty meeting National Health and Medical Research Council standards in the Upper Blue Mountains supply system, the board explained that the problems were caused by the fact that the water supply for the Upper Mountains came mainly from a relatively complex series of small catchments, which had mixed degrees of residential and other development and treatment.

"High levels of iron and maganese occur naturally in the area and are characteristics of the water supply and all water is very 'soft' and aggressive and therefore corrosive to most types of piping," the report said.

"As well, during storms overall run-off causes increases in turbidity (a possible source of disinfection of the supply) and 'boil water' warnings are issued as a precaution against possible health risks.

"Woodford Creek has considerable residential development with many properties having septic tanks, water from this catchment is fully treated and disinfected prior to use."

The report noted that service reservoirs were generally in poor condition as was the reticulation system.

It pointed to problems associated with unlined piping, no flushing hydrants at dead ends allowing sediment to build up.

According to the report, the Board proposes to immediately institute a community education/interaction process to improve land management practices in the catchments and to conduct further mains cleaning and lining of unlined mains along with improvements to raw water storages.

In the short term, interim treatment facilities are being installed at Greaves Creek and Lake Medlow as a major priority; the remainder of the service reservoirs are being roofed and the system upgraded to allow effective cleaning and innovative mains rehabilitation processes were being actively pursued.

In the Lower Mountains the board reported the major problem to be the fact that, due to increased development, the treatment plant at Orchard Hills had difficulty coping with peak demands.

The board proposes further upgrading of the plant which it hoped would be completed soon along with the operation of the reticulation and service storage reservoirs.

This, it was hoped, would optimise drinking water quality.

In the medium term the board proposed upgrading of the Stage 2 of the treatment works, the pursuit of innovative solutions to accelerate improvement and increase the ability of the total system to be more flexibly managed.

Overall, long term spending includes $10 million to spent on 50 ML/D treatment works at the Leura Cascades and $40m for treatment facilities at Greaves Ck and pumping stations and rising mains necessary to get treated water from Cascades and Greaves Ck into the Upper Mountains.

BLUE MOUNTAINS GAZETTE
2.5.92

Board improves water

The Water Board has called tenders from companies to install a prefabricated filtration plant to improve water quality for residents from Medlow Bath to Mt Victoria.

At the same time, the Water Board has appointed consultant engineers Sinclair Knight and Partners to assist with concept design investigation and work for a larger system to improve water quality in Katoomba and the Central Blue Mountains by the end of 1992.

Tenders for the installation of the filtration system to the Lake Greaves Reservoir, which services Mt Victoria, Blackheath and Medlow Bath, will close in early March, with work expected to start in July.

Water Board managing director, Bob Wilson, told local member, Barry Morris that the 5,000 people in the Upper Blue Mountains receive the worst quality water in the whole of the Sydney, Illawarra and Blue Mountains areas.

A recent internal Water Board report focussed on the high iron and manganese levels in the storages of Lake Medlow, Lake Greaves and the Cascades Dam.

"Though the color of the water is not a health problem, it does cause concern to Blue Mountains people," said Mr Wilson.

"The pre-fabricated filtration plant at Greaves Creek, which is expected to cost around $3 million, will be adequate for all but four or five weeks of the year when it will be necessary to "top up" supply to avoid low pressure during peak demand periods.

"Because of the size of the filtration plant, it can readily be fitted into the existing site with minimal environmental disturbance.

"The Cascade System services about 12,000 people from Katoomba to Linden. Because of the size of the system, a pre-fabricated plant is not considered viable.

"Instead, the Water Board is fast tracking the investigation, design and review of environmental factors towards building a permanent filtration plant.

"The plant will cost around $10.5 million, with the investigation work being completed by March, and commissioning by December, 1992."

Mr Wilson said that the schemes were part of a major Water Board initiative to improve water quality in the Blue Mountains.

He explained that expressions of interest were being accessed from companies all round Australia interested in carrying out relining work on reticulation mains in the Upper Blue Mountains.

"The mains and fittings are made of unlined cast iron, the earliest of which was laid in 19[illegible]. The deposits inside the pipes build up and cause loss of pressure. Then the deposits are released, colouring the water black or brown.

"About 50 kilometres of piping in various locations between Mt Victoria and Wentworth Falls will be treated. The relining work will be completed by 1992 at a cost of about $5 million."

Welcoming the announcements, Barry Morris said, "The Water Board took over responsibility in 1980 for supplying water to the Blue Mountains knowing that there were serious problems.

"All this work is needed to address these problems and to maintain the Blue Mountains reputation as a premier tourist attraction. This Government has made a major commitment to preserving the environment of the beautiful Blue Mountains for the benefit of both residents and visitors."

BLUE MOUNTAINS GAZETTE
30.12.92

Work on dams will improve water quality

Work on six storage dams in the Blue Mountains have been completed which will result in better quality water for householders, State Member Mr Morris said this week.

"The work is to destratify the three Cascade Dams, the Woodford, Medlow and Greaves Creek dams to try to reduce the iron content in the water," Mr Morris said.

"In recent months the natural iron in the dams has been a problem for the Water Board in trying to maintain the clarity of drinking water in the Upper Blue Mountains.

"Now Environment Minister Tim Moore tells me that work on improving the supply has been completed.

"A total of $186 000 has been spent installing the equipment into each of the water storage areas."

Mr Morris said that in recent months Blue Mountains residents had experienced poor quality water because of the high natural iron content in the dams.

Very soon, because of cooler temperatures the dams will naturally 'turn over' allowing the iron to settle to the bottom. In the short term this will resolve the problem.

But, Mr Morris said, when the warmer weather begins again, the destratification equipment will show real benefits.

The destratification process means equipment has been installed at the bottom of the dams to turn the water over. This can be started up at the flick of a switch.

This will allow the Water Board to maintain consistent oxygen content in the stored water reducing the amount of natural iron in the water.

BLUE MOUNTAINS GAZETTE
_30.6.90_

Anti-fluoride case begins in Katoomba

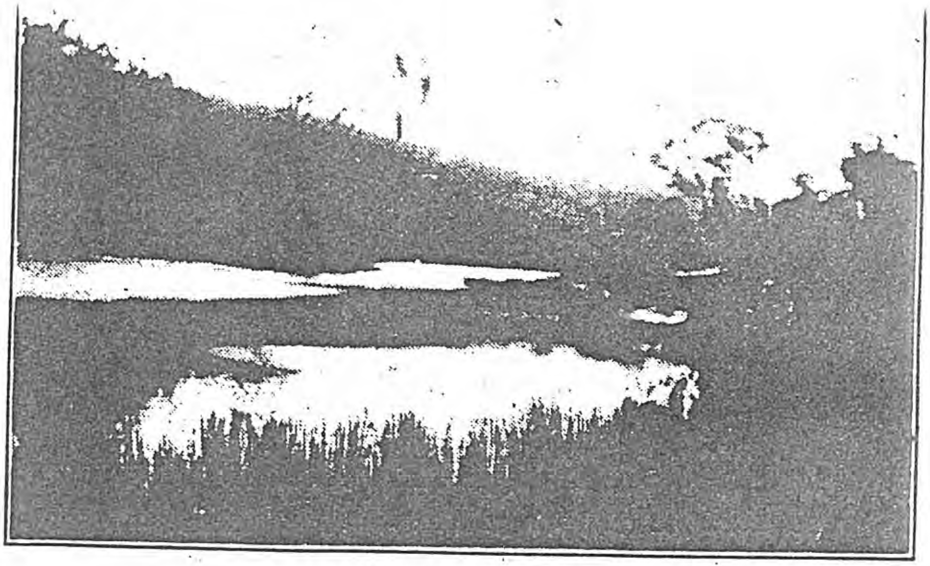
The court case resulting from the anti-fluoride demonstration at Medlow Bath in April began in Katoomba Court last week.

Police spent Monday, Tuesday and Wednesday of last week tendering evidence in the case which has been adjourned to Friday, September 25.

When the case resumes police will tender more evidence, followed by the Water Board. Protesters will then have their say.

On each day of the case last week the court room was filled, with people sitting on the floor of the court.

BLUE MOUNTAINS GAZETTE
_22.7.92_



LAKE MEDLOW, MEDLOW BATH

The Premier Visitors' Pleasure Resort of the Blue Mountains

Illustration from Cover of *The Blackheath Bulletin* in January 1931

Lake Medlow.—A gigantic sheet of water, dammed back by a narrow concrete wall over 70 feet in height. This lake is the source of the town water supply, and teems with fine rainbow trout. Its spillway is a picturesque cascade, and a few hundred feet below the dam head lie Wall's Cave and the entrance to the Grand Canyon.

Description of Lake Medlow appearing on the front cover of every *Blackheath Beacon* in 1930 as a "Principal Sight" of Blackheath

Hikers at Hydro

Colourful Spectacle

Last week-end, Palmer's of Sydney organised an official hike to the beauty spots of Medlow Bath.

The party, 120 strong left Sydney on Saturday on the 1.15 train and arrived at about 4 30 p.m. at the Hydro.

Mr. J. A. Fullarton, manager of Palmer's sports goods department had charge of the party, and the first hike started off from the Hydro at 9.30 a.m. Sunday.

The objective chosen was Lake Medlow, and the whole party started off under Guide Richardson punctually.

Crossing the railway line opposite the Hydro, the party streamed along bearing to the right down the road past Griffith's Farm.

The cavalcade was in merry mood, and song and chorus made the journey to the lake and Wall's Cave all too short.

After a breather at Lake Medlow, the party returned in easy stages and reached the Hydro for lunch, where the tempting fare on the menu was done more than justice.

After lunch, the party assembled in front of the Hydro and a photograph was taken for the press by Mr. Manning. Several other "shots" were taken of the party "en-route" during the afternoon hike. Past the coal mine, the party swung up through the the delightful Blackheath Glen.

The Mermaid's Cave was visited, and the hike moved along towards Blackheath and turned off at the short cut through Wonderland.

Report of a Walk to Lake Medlow in *The Blue Mountains Times*, 28 October, 1932

(OUTSIDE OUR OWN GROUNDS)

No. 7 PATH—MEDLOW BATH LAKE

Cross over by the turnstile opposite Hydro on railway. Bearing always to the right hand, go down road past Griffith's Farm, and on along to gate in golf links. Through golf links to other side or end, and on straight or nearly straight down, and down to The Lake. About 6 miles return.

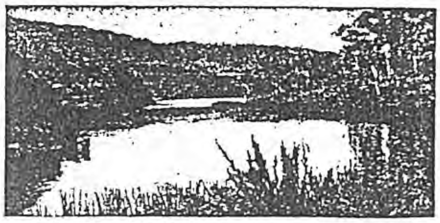
No. 8 PATH—GRAND CANYON, WALL'S CAVE AND LAKE MEDLOW

Road as No. 7 to golf links, but do not enter the gate. Go straight along the road past the golf links fence, and bear to the right after you leave the golf links for one mile. Then slightly left and down, and down gradually past Pilcher's Lookout, down to the lovely Grand Canyon—one can walk up stream to Wall's Cave and Lake Medlow, and back to Hydro through the golf links.

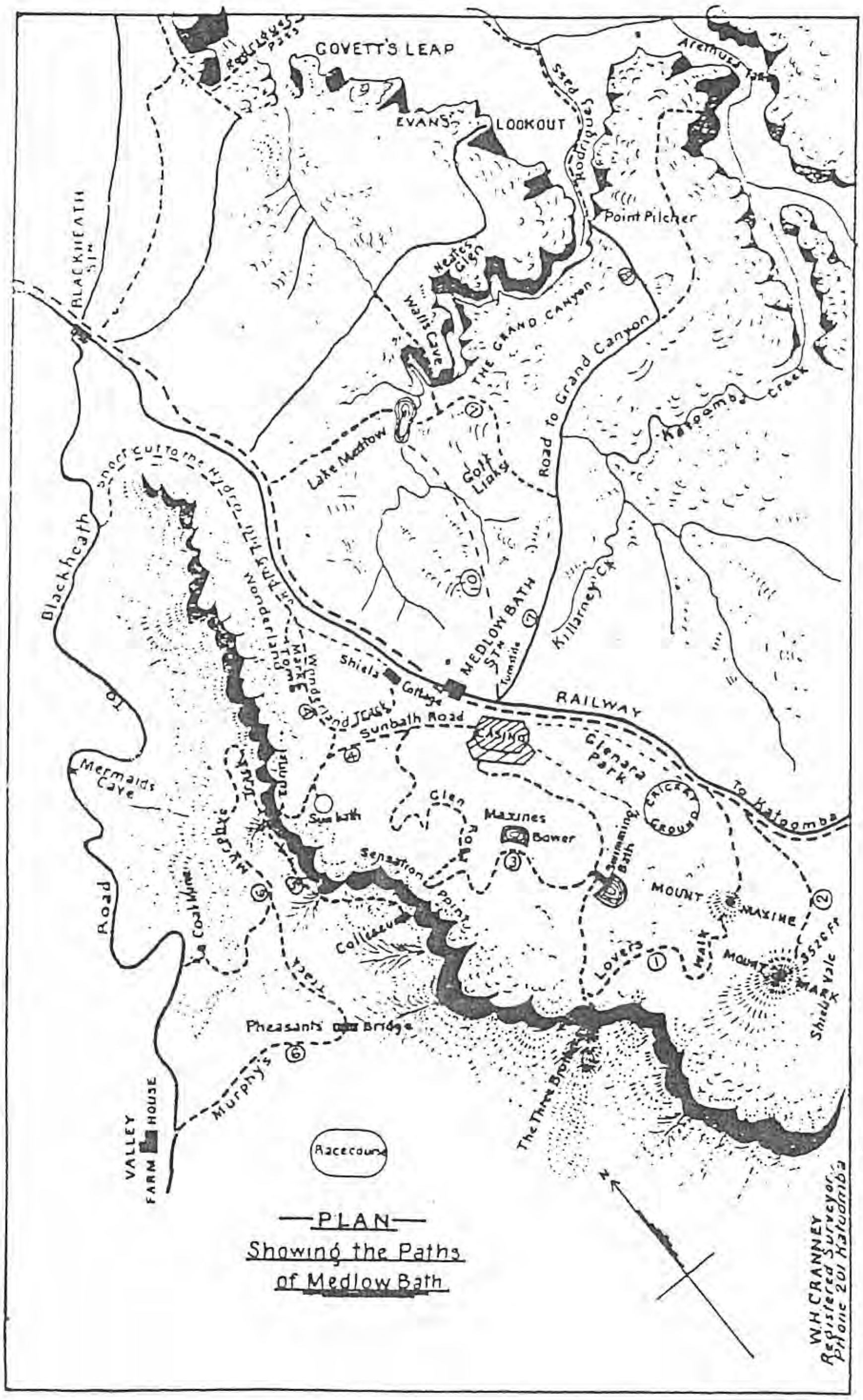
No. 10—THE BRIDLE TRACK TO LAKE MEDLOW

Cross over the railway by the turnstile, and go straight ahead down across a dry creek; then on up the hill, keeping as straight as possible, and looking out for the sign-boards. You will get on to this bridle track to the Lake, which is much nearer than going round by the golf course.

Distance, 3 miles return.



Lake Medlow.



Walks Described in *The Blue Mountains at Medlow Bath*

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